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EFFECTS OF AGRICULTURAL DEVELOPMENT ON VECTOR-BORNE DISEASES

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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EFFECTS OF AGRICULTURAL DEVELOPMENT

ON

VECTOR-BORNE DISEASES

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JOINT WHO/FAO/UNEP PANEL OF EXPERTS ON ENVIRONMENTAL MANAGEMENT FOR VECTOR CONTROL

The WHO/FAO/UNEP Panel of Experts on Environmental Management for Vector Control (PEEM) was established in 1981 according to the Arrangements agreed upon by the three participating organizations.

The objective of PEEM is to create an institutional framework for effective interagency and intersectoral collaboration by bringing together various organizations and institutions involved in health, water and land development and the protection of the environment, with a view to promoting the extended use of environmental management measures for vector control within health programmes and in development projects as health and environmental safeguards.

This paper, prepared by FAO, contains the Working Papers presented to the 1987 PEEM Technical Discussion on "Effects of agricultural development and changes in agricultural practices on the transmission of vector-borne diseases", together with a brief summary of the conclusions of the Discussion. It is hoped that it will stimulate interest in the study, development and application of environmental management techniques in conjunction with agricultural production.

CONTENTS

I. INTRODUCTION

The Panel of Experts on Environmental Management for Vector Control (PEEM), holds a Technical Discussion as an established feature of its annual meetings. For the Seventh Meeting, held at the FAO Headquarters from 7 to 11 September 1987, the selected subject was "Effects of agricultural development and changes in agricultural practices on the transmission of vector-borne diseases".

The Working Papers submitted for discussion covered a wide range of issues relating such developments and changes to proven or potential impacts on diseases. Prominent among these were the environmental and ecological effects created by the introduction of high yielding varieties (HYVs) of crops, especially rice, which demand more intensive inputs and management than the traditional varieties, particularly in terms of water supply and protection from plant diseases and pests. The question of pesticide use and its possible impact on disease vectors has always been of considerable concern to PEEM and was treated at length in the papers, with proposals for a strategy of integrated pest management for both agricultural and human health objectives.

The papers illustrated the close links between vector ecology and agricultural water development and management, with drainage as a key factor in determining levels of vector production. In the case of irrigation, attention was focused on rehabilitation, improvement and operation, and also on the potential and constraints for farmer collaboration in crop water management. This last aspect was one of a number of examples showing the need for detailed social and demographic studies of all affected strata of human populations in work on vector control and disease transmission. Other examples related to mechanization; land clearing; new patterns of land use; and conjunctive production of fish and food crops.

Because of the special relevance of the Discussion to many FAO activities, it was decided to publish the Working Papers, and a summary of the conclusions, in the AGL series of documents. Some editing and condensation has been necessary to keep within the limits specified for the publication but all original references are listed. Unabridged versions of the Working Papers may be obtained from PEEM Secretariat, VBC Division, World Health Organization, Geneva.

II. THE TECHNICAL DISCUSSION

The Technical Discussion concentrated on two main areas, information requirements (and their presentation) and applicable techniques.

1. Information requirements

It was recognized that future agricultural development will include new developments and modernization of existing ones. New developments require a health risk assessment, for which PEEM prototype guidelines are under evaluation. In contrast, for modernization of existing programmes, the health and vector status may already be definable. In all cases, however, changes in existing land use represent the beginning of a dynamic process of ecological change associated with demographic changes and changes in vector species composition and abundance. Such changes are complex, occur over different timescales, must be considered in local context, and require appropriate monitoring and surveillance systems to provide the required information.

Recognizing the different needs and budgetary constraints specified by the overall size of each project, it was concluded that specific information requirements should include the following:

(a) Physical aspects of changes in land use. Physical changes within the agricultural context specifically alter the availability of vector breeding sites and the opportunities for human-vector contact. This seems particularly apparent at the margin between development and an established environment. Procedures for survey of such margins, and for monitoring changes in relation to vector and host behaviour, should be encouraged and, wherever possible, incorporated as part of a regular surveillance system.

(b) Demographic changes. Agricultural developments frequently involve human migration, seasonal labourers and changes in settlement patterns. Intrinsic cultural aspects, siting of settlements and migration can play a key role in the spread of parasites and vectors, and in defining levels of man-vector and man-pathogen contact. Special attention was given to the need for detailed study of all strata of human populations, because of the diverse characteristics and perceptions of age-group, sex, and occupation which can condition exposure and susceptibility to infection.

(c) Vectors and diseases. The need for accurate identification of vectors, their habitats and their natural enemies was repeatedly emphasized, especially where sibling species of different vectorial capacity may be involved. Accurate quantification of infection rates was also stressed, yet it was noted that considerable site, disease and vector-specific variation exists in the quantitative relationship between vector abundance and parasite transmission. Three key areas for further study were therefore identified: methods for long-term quantitative surveillance of vectors and their natural or introduced enemies (including better information on natural enemy impact); accurate identification methods applicable to field situations; and the relationship between vector density and transmission. The latter was felt to be particularly important with regard to proposals for integrated pest management which require information about how any reduction in vector abundance will affect disease transmission (see below under IPM).

(d) Organizational involvement. Agricultural development generally requires multidisciplinary interaction between several government and non-government agencies. Coordination of their activities can be difficult - due to communication problems and conflicting budgetary requirements - and requires careful identification of the institutions and personnel involved, noting their operational priorities, constraints and decision-making criteria. Evaluation of institutional responsibilities within an agricultural development will help to define the specific levels of information they require, and how such information can be best presented.

The Discussion stressed that while the quality of information was a key issue, its mode of presentation was of parallel importance and would influence the way the information would be used. It also stressed the need to identify clearly the institutional audience for each component of the information, so that volume, form, and level of interpretation could be presented in the most effective way.

It was noted that the policies of major investment agencies (including national governments) usually differentiate between the components of agricultural projects that have a primary production purpose, and those with a clear social and health objective. Often, this permits separate consideration of the latter - even allowing the direct costs of investment for health to be excluded from estimates of the economic rate of return of the project. Nevertheless, some essential components such as housing and associated services can have a profound effect on the economic analysis (sometimes representing 25-30% of total project cost) and may therefore be provided at a standard inconsistent with good environmental health.

For this reason, the Discussion emphasized the importance of clear identification of specific project components - relating them to their association with health issues, their economic and social priority, and to the organizational responsibility for each component. It was proposed that PEEM highlight those components essential to the aims of vector control and for wider community health benefits, indicating where feasible the relative benefits that may be derived from various components within specified budgetary constraints. Where several options seem available, PEEM should focus attention on those most compatible with sound environmental management for vector control.

2. Techniques

* Impacts of agricultural pesticides

The PEEM objective to promote environmental management for vector control is largely in response to the undesirable effects of pesticides on vector resistance, on the environment and on human health. Agricultural development and changes in agricultural practices have shown a marked trend to increased use of pesticides, especially in irrigated agriculture where some vectors breed, with a known excessive use in many cases and often with considerable confusion regarding optimum applications. This overuse may sometimes be associated with pesticide subsidies which make farm usage an inexpensive option.

Attention was drawn to the International Code of Conduct on the Distribution and Use of Pesticides, prepared by FAO in conjunction with other international organizations, and adopted by the FAO Conference in 1985. This Code, with widespread support from Governments, serves as a point of reference until such time as countries have established adequate national regulatory infrastructures.

In view of the existence of the Code, and the complementary objectives of the FAO/UNEP Panel on Integrated Pest Control and Plant Breeding, it was agreed that PEEM should collaborate closely with that panel in joint efforts to encourage more rational pesticide use in order to reduce potential vector hazards and to promote control through environmental management measures where appropriate. To this end, PEEM should examine specific ways in which vector control can be included within Integrated Pest Management (IPM) strategies.

* Impacts of high yielding crop varieties (HYVs)

It was recognized that the introduction of HYVs has a profound impact on agricultural practices, especially with regard to rice in Asia. The potential of such varieties can only be best realized under optimal growth conditions but does not necessarily require the high use of pesticides as is often assumed.

Discussion revealed that HYVs are not necessarily appropriate for all situations and are not always accepted by farmers for various physical, social and economic reasons. The development of HYVs with lower water requirement would be highly desirable.

Agricultural practices for HYVs may not be compatible with the use of ricefields for fish production. Appreciating the advantages of HYVs for rice production, but also aware that fish may have the dual role of food protein and enemies of disease vectors, it was felt that there is a need to investigate whether the higher pesticide input in HYVs fields might have led to a lower fish yield as compared with that from ricefields under the lower pesticide applications usually associated with growing traditional rice varieties. This could be a first step in the evaluation of IPM strategies for vector control in rice fields.

* Irrigation and drainage schemes

(a) Irrigation development

The global trend in irrigation development is towards a reduction in the rate of expansion of new, major schemes, greater emphasis on the rehabilitation and improvment of existing schemes, on changes in management methods and organizational arrangements and, in many countries, greater attention to small-scale irrigation projects. This was perceived as having implications for PEEM's work on forecasting guidelines, which should respond to these needs and should be tested for their applicability to the different circumstances and for their treatment of operational aspects in addition to planning, design and structural elements.

(b) Irrigation practices

The term "alternate wetting and drying" (AWD) was adopted to describe the vector control measure sometimes used in ricefields, rather than "intermittent irrigation" which also indicates a different practice of water supply.

The use of alternate wetting and drying of ricefields, which has received considerable publicity as a control technique, is accepted as a suitable measure where land, soil, crop and water conditions are appropriate but, as with many other control methodologies, its use is constrained by site and vector characteristics.

In general reference to water management practices applied as vector control measures in irrigation, it must be recognized that the ability of a system to control the supply of water to the farmer may not be accompanied by his ability or willingness to apply crop/water management techniques for vector control, especially where schemes are farmed by smallholders. This calls for dialogue with the farmers to identify possibilities and constraints of such methods.

(c) Drainage

In irrigation schemes in particular, but also in other agricultural development where excess water may pose a problem, drainage has been clearly identified as a major factor determining or controlling health risks. The same is also true in the case of rural and other settlements. The absence of a drainage system may cause problems through the accumulation and persistence of stagnant water on the land surface. Where an open drainage system exists, there may be different problems due to stagnant or slow-moving water, and weed growth, in those drains. It is therefore proposed that this aspect be given greater emphasis and publicity by PEEM as a subject with special relevance in programmes related to environmental management for vector control. The WHO Manual of Environmental Management for Mosquito Control, prepared with FAO collaboration, is a particularly relevant source of information.

(d) Economics of health measures in irrigation

Because of the trend to reduction of investment in this relatively expensive form of agriculture and the consequent increased need to target limited financial resources to best effect, the recommendations arising from the sixth PEEM meeting regarding the necessity to identify and quantify potential health consequences due to irrigation were reiterated. So also was the need for continuing with efforts to formulate methods for the application of cost-effectiveness and, where possible, cost-benefit analysis to the selection of the most appropriate forms of vector control in specific project circumstances.

* Mechanization

The diversity of economic, social and ecological consequences arising from the introduction of mechanized power makes it difficult to predict its effect on vectors, and many possible influencing factors were cited. Among these were the direct effects of mechanization relating to vector habitat, such as an increase in cultivated area, greater number of crop cycles and changes in superficial water patterns which may affect large areas under irrigated agriculture or small depressions such as wheel ruts, both of which have been known to have marked impacts on specific vectors. Also considered were the reduction in animal populations and usage; redeployment of labour force; reduced human/vector contact and, for some strata of the population, increased leisure time and improved standards of housing and services.

III. WORKING PAPERS

1. PAST, PRESENT AND FUTURE NEEDS IN LAND AND WATER DEVELOPMENT FOR FOOD PRODUCTION - IMPLICATIONS FOR RURAL DEVELOPMENT, ENVIRONMENT AND THE VECTOR-BORNE DISEASE SITUATION

Asit K. Biswas[1]

Introduction

The complexities of issues and problems associated with the interrelationship between people, resources, environment and development constitute a subject that is fa from new. What is new, however, is the recent recognition of their importance. Ne too, is the gradual recognition that these interlinkages are important for th development process.

There is an increasing realization that for sustainable development the variou interrelationship issues can be best understood and dealt with in a holistic approac that considers an overall framework of the web of causes and effects that binds the together. In this sense at least the interrelationship concept can be considered to b of a wholly new character, and may require not only better understanding through the availability of new information but also development of new attitudes and perceptions.

Land and water development for food production

There are some natural constraints to increasing food production, such as availability of good agricultural land, reliable water supply and climate. Beyond these constraints, man dictates the pattern of development. Furthermore, food is a net product of an ecosystem, and as long as the ecosystem remains healthy it will continue producing the expected amount of food. Improper management practices, however, can undermine the viability of the agricultural system in various ways.

Reliable water supply is an essential condition of any efficient agricultural production system. Optimal production of high-yielding varieties of crops is only possible with properly controlled water supply schemes. Even though only about 15% of the world's cropland is irrigated, it yields from 30% to 40% of all agricultural production. A clear picture of the contribution of irrigation in creating food self-sufficiency can be demonstrated by considering what has happened in India during the past two decades.

In the mid-Sixties, agricultural production in India was not sufficient to sustain her population. Yet within two decades, and in spite of a large population and continuing high population growth, the food situation has changed dramatically. By 1986, India was trying to export nearly one million tons of wheat. This was made

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possible by both horizontal and vertical expansion of agriculture through extensive irrigation development. The irrigation potential has increased some three-fold during the period 1950 to 1985. In addition to this horizontal expansion, crop yields in irrigated areas have been substantially higher than in non-irrigated areas. Even if the extent of irrigated and non-irrigated areas of rice cultivation, by the Seventh Plan, are expected to be somewhat similar, (21.5 million and 22.5 million ha) irrigated rice production is likely to be almost double the non-irrigated production, (48.1 and 25.9 million tons respectively). Yields of other crops in irrigated areas are also higher than in non-irrigated areas.

Impact of land and water development on rural development, environment and health: recent trends

Any reasonable size land and water development project will have discernible impacts on rural development, environment and health, though the magnitude and extent of these will vary from project to project. With respect to irrigated agriculture projects the word "impact", at least in recent years, has developed primarily negative connotations. This emphasis on negative factors of projects and programmes is not difficult to explain. In the 1960's analyses of irrigated agriculture projects considered primarily technical and economic factors: environmental and social issues were generally ignored. Concerned with the adverse effects of many development projects on society and the environment, a movement gradually developed to protect and preserve the environment.

This attitude was reflected in the United Nations Conference on the Human Environment, held in Stockholm in 1972. An analysis of the Stockholm Action Plan would clearly indicate its negative approach to environmental management - stop all pollution stemming from any development activity, stop exhausting non-renewable resources and stop using renewable resources faster than their re-generation. The emphasis thus was primarily on adverse impacts of development.

Another event of this period was the publication of a series of articles by Claire Sterling in the popular media, on the adverse social and environmental impacts of the newly built Aswan Dam in Egypt. By drawing attention to these issues, it was made clear to the engineering profession, which dominates the water development field, that there are other important dimensions, in addition to the techno-economic ones, in which society is interested. Accordingly, increasingly more environmental and social impact analyses of water development projects have been carried out during the past decade. However, the emphasis has continued to be on the identification of negative impacts and ways to ameliorate them.

A further issue is the sectoral approach to land and water development. Large or medium scale projects not only increase agricultural production and change the environment, but also have substantial impacts on factors such as employment generation, education, health facilties, communications, energy availability in terms of fuelwood and electricity, domestic water supply and women. These impacts are not always easy to identify or predict. They may also vary substantially in their nature and magnitude from one project to another. Unfortunately, holistic approaches to land and water development that consider all these factors are few and far between.

There are many reasons for this state of affairs, but one of the most important is the division of responsibilities among various national ministries. And yet, in any large scale land and water development, all these factors and issues must be integrated within the project. It has to be admitted that there are not many success stories.

Even if one single field like health is considered, there are many issues that should be reviewed but generally are not. Because of the emphasis on negative impacts, the health issues usually considered are the adverse ones, e.g., increases in vector-borne diseases such as schistosomiasis and malaria.

It is very rare to find projects where health considerations include improvements due to more assured and varied food supply available to the people through increased agricultural production, fish catches in man-made lakes, and livestock holdings. Improvements in health due to secondary factors like better transportation and communications in the project area, new education and health facilities and improved status of women are rarely taken into account. But in terms of overall health in the project area, these factors are more important than a single factor, such as an increase in vector-borne disease prevalence. Even for that single factor much of our information is anecdotal and thus inadequate for decision-making processes.

Irrigation development, environment and public health

There are three important issues to note in any discussion of the implications of irrigation development on the environment and vector-borne diseases. Firstly, the impacts of land and water development on the environment and on public health are many. Some are direct and are comparatively easy to predict. Others could be indirect and project-specific, and thus may often prove to be difficult to foresee and even more difficult to quantify. Most water resources projects produce a mixture of these two types of impacts. Considering the methodological limitations that are inherent in such impact analyses, it is a difficult task under the best of circumstances.

Secondly, environmental and health impacts of projects, both direct and indirect, are never confined within the project boundary. Many occur far from the project area. Accordingly, it is not possible to define a precise geographical boundary which can be said to contain all the impacts. Thirdly, the time dimension of impacts is another complicating factor. Certain impacts can be immediate, and thus can be identified during the implementation phase or soon after. Others, however, could be slow to develop, and may not be visible in the early stages. A typical case is salinity development in irrigated areas, which could take 15 to 20 years in some projects while in others the problem may appear within 2 to 3 years, depending on physical conditions, drainage facilities, and operational procedures.

Vector-borne diseases

The interrelationships between people, irrigation development and vector-borne diseases are complex, and it is difficult to paint a comprehensive picture because of the limiting state of existing knowledge. A cursory analysis of the present literature will indicate the preponderance of a traditional and simplistic approach which basically concludes that irrigation projects increase the incidence of vector-borne diseases. The available literature will also give a plethora of statements and so-called facts and figures on the increase of vector-borne diseases following the construction of irrigation systems. While it is accepted that such general statements had a role to play in the 1960's and 1970's to sensitize engineers, decision-makers and the general public on the importance of the consideration of vector-borne diseases, it is submitted that very little further progress has been made in the 1980's to provide the specific information needed to improve planning and management processes.

One of the major problems with respect to the incidence of vector-borne diseases in irrigation projects stems from the lack of an adequate number of scientifically rigorous studies.

A second problem is the absence of data of pre-project conditions on environmental and health-related factors. Even now, when some base-line surveys are being carried out to establish initial conditions, environmental and health issues receive virtually no attention. It is not then possible to say with any degree of certainty how vector-borne diseases have increased or decreased over time in a project area. A third problem arises from the fact that objective and comprehensive evaluations of irrigation projects, including incidence of diseases, are never carried out at regular intervals.

Finally, emphasis on vector-borne diseases due to irrigation projects is based on a very narrow perspective. It is **a priori** assumed that the impact is always negative. This assumption is difficult to justify, since the health of people in a project are depends on a multitude of factors, among which are employment and income generation, status of food availability and nutrition, education, impact on women and on the environment and changes in the overall quality of life. An integration of all these factors will determine the health of the people. Since they will all change with the introduction of an irrigation system, a simplistic approach, such as is generally considered at present, can no longer be accepted as adequate. A more realistic framework needs to be developed urgently for the analysis of health issues.

2. MODERN RICE TECHNOLOGY AND ITS RELATIONSHIPS TO DISEASE VECTOR PROPAGATION

S.I. Bhuiyan[1] and B.M. Sheppard[2]

Introduction

The widespread adoption of modern rice technology in Asia has made it possible to keep up rice production with the increased demands during the past two decades or so. Central to the modern rice technology is the development of the high yielding varieties (HYVs) which replaced traditional rice varieties in farmers' fields in most of the major rice-growing countries. With the realization that successful cultivation of the HYV rice requires adequate and controlled water in the ricefield, development of irrigation facilities was given major attention in these countries (Table 1). The results were impressive. Average total quantity of rice produced in Asia in the period 1971-1980 was 77% higher than that of the period 1951-1960 and 35% higher than that of 1961-1970 (Barker **et al.**, 1985). The HYVs, irrigation water, and fertilizers - the three major inputs to the production system - contributed almost equally to these production gains.

Little concrete information seems to exist to support the notion that increased plantings of HYVs **per se** have increased malaria incidences in rice-growing areas, although circumstantial evidence indicates that expanding irrigation may be an important contributor to the problem (Chapin and Wasserstrom, 1981; Goonasekere and Amarasinghe, 1987). In China, a double-peak pattern of adult mosquito density has been observed in double-cropped areas, in contrast to a single-peak pattern in single-cropped areas (Lu, 1987). On the other hand, the frequency with which the tropical paddy fields themselves have been found free from dangerous anophelines has surprised malariologists (Najera, 1987).

In this paper, we emphasize the HYVs, water management and insect control measures of modern rice technology in relation to vector propagation and control potentials. Because of the overwhelming importance of mosquitos as vectors in the South and South East Asian rice-growing regions, where the modern rice technology has found most adoption in recent years, we have confined our deliberations to mosquito vectors only.

Characteristics of HYVs

It is important to recall here several major characteristics of the HYVs of rice:

First, the HYVs have shorter growth durations than most traditional varieties which may require 150 to 180 days to mature. This trait enables a farmer with access to irrigation water to grow two to three crops a year.

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Table 1. Growth in irrigated areas in Asia. (Modified from Barker et al., 1985)

Country	Irrigated area (thousand ha) 1960	1980	Annual growth (%)
Island and peninsula countries			
S. Korea	663	1 150	2.8
Malaysia	214	370	2.8
Philippines	808	1 300	2.4
Sri Lanka	255	525	3.7
Indonesia	4 100	5 418	1.4
Major river delta countries			
Bangladesh	316	1 620	8.5
Burma	545	999	3.1
Thailand	1 636	2 650	2.4
Vietnam/Kampuchea/Laos	n.a.	1 700	-
Continental diversified-grain countries			
China	32 900	48 000	1.9
Nepal	n.a.	230	-
Pakistan	10 234	14 300	1.7
India	23 393	36 665	2.3
South and Southeast Asia	41 501	65 777	2.2
Total	75 064	112 997	2.1

n.a. = not available

Second, the HYVs, unlike the traditional varieties, are insensitive to photoperiod or day length. This trait allows them to be grown well during any period of the year.

Third, the HYVs tiller more, have shorter and stiffer stems, and bear heavier panicles without lodging. This is the characteristic that is mostly responsible for higher yields per unit of land use. Furthermore, it is important to note that as a result a rice field is almost completely shaded by foliage within about 40 days after transplanting.

Fourth, the HYVs are in general sensitive to water shortage or drought. Water stress at any growth stage may reduce yield, but the plant is most sensitive to water deficit from the reduction division stage to heading. The stress at this latter stage can not be compensated by the plant and causes spikelet sterility (Yoshida, 1981).

Fifth, most of the HYVs have various degrees of built-in resistance to a wide range of insects. Thus, they should require less amounts of insecticide application to avoid crop damage.

Water management and vector control

The primary concern with water in rice fields relates to its abundance and long duration, which are favourable to the breeding of mosquitos. It takes about 9-14 days to complete the reproductive cycle of a mosquito, from the ovulation to the adult mosquito stage. Since rice fields are most often kept flooded with shallow depth of water for almost the entire duration of the plant growth, many life cycles could be completed during a growing season. Fields grown to a second or a third crop of rice could become almost a perennial ground for multiplication of mosquitoes.

The mosquito reproductive cycles can be interrupted and existing eggs and larvae could be destroyed if the rice field is allowed to dry up in a cyclic time sequence. Will such a practice be compatible with the optimal performance of the HYVs? What may be the effects of adopting such a practice on the amount of water needed to grow the rice or on other crop management practices? An understanding of these questions, their possible answers and implications is important for developing appropriate and sustainable strategies to control rice field vector propagation.

* Water management for modern rice production system

Rice is an aquatic plant and generally grows well in water-abundant situations. Unlike most other cereal crops, the rice plant is endowed with the unique ability to transport oxygen through its leaf blade and leaf sheath stomata and supply it to the roots to avoid suffocation of the root tissues in submerged soils.

Soils under shallow submergence are found more favourable to rice culture because submergence facilitates the availability of several nutrients from the soil, including nitrogen and phosphorus (Yoshida, 1981); Additional major practical benefits from submerging rice fields are the better control of weeds (Rao and Moody, 1986) and a greater insurance against drought or water shortage. Thus continuous shallow submergence has been the standard water management practice for irrigated rice production in normal soils in almost all tropical areas. In rainfed areas, rice farmers strive to impound rainwater to a greater depth as an insurance against uncertainties of water supply.

The rice field water requirements are composed of two components: evapotranspiration (ET) requirement of the crop, and seepage and percolation (S&P) requirement of the soil. The ET is an environmental demand on the crop and the area it covers. Thus, ET is influenced by such climatic factors as solar radiation, humidity and wind speed. The S&P loss is most often considered unavoidable because, in the usual irrigation method practised in ricefields, the natural downward flow through the soil profile can hardly be reduced.

Water status manipulation in rice fields should be done in such a manner that the ET rate of the crop is not reduced because an unhindered ET is essential for the crop to produce high grain yields.

Among the HYVs available for irrigated rice, none has been especially developed to tolerate intermittent or prolonged droughts. One or two of the available modern varieties (for example, IR36) are known to have a somewhat greater degree of drought tolerance compared to the others, but it was per chance rather than by design. No such development has taken place in the Asian tropical rice scene.

* Rice field water manipulation for vector control

The central question of practical significance in this respect is: can rice fields be kept without standing water long enough without detrimental effects on yields? Will such a method require more or less water than the standard practice? Basically two types of water regime manipulation are relevant in seeking a solution of the problem.

1. Alternate wetting and drying of ricefields

In this method irrigation water is withheld (or rainwater drained) with a planned regularity. In some literature, this method has been termed "intermittent irrigation". We think the term "alternate wetting and drying" is more appropriate because it expresses better what is done in the field and also because the other term can be quite appropriately used for such irrigation practices as delivering water intermittently, without necessarily creating dry conditions.

This approach should be highly effective in mosquito breeding control in rice fields provided the drying cycle is long enough to destroy the larvae and the wetting cycle short enough not to allow mosquitoes to multiply. A number of investigations were carried out in different countries using this general approach The research findings may be summarized as follows:

- Significant water savings were achieved using this approach in comparison with the standard continuous shallow submergence practice (Hill and Cambournac, 1941; Sandhu **et al.**, 1980; Jha **et al.**, 1981; Lu, 1984).

- The reported effects on yields are varied. Only in the Chinese study reported by Lu (1984) were higher yields reported from the practice of alternate wetting and drying. In the other cases, yields were either comparable or lower than those obtained under shallow submergence conditions. The reasons for the differing results are not clear. It is possible that differences in soil type, its mineral and organic matter content, temperature regime and their interactions may play a role.

- None of the reported research has determined the relationships of the water management practices to the management of other inputs in the ricefields. The effects of alternate wetting and drying of ricefields on fertilizer uptake and weed control measures are especially important.

- In several studies, a very high degree of mosquito larva control was achieved with alternate wetting and drying of rice fields (for example, Hill and Cambournac, 1941; Lu, 1984), establishing that periodic wetting and drying is an effective means for control of mosquito propagation in rice fields.

From the practical implementation viewpoint, this method has the limitation that it requires a complete system of irrigation and drainage which is often lacking in the rice irrigation sytems and it needs the services of well-trained irrigators. A more widespread problem is associated with unreliability in the supply of water to the various parts, especially in the tail-end, of the irrigation systems.

2. Maintaining soil saturation

If this method can be practised properly it will eliminate mosquito reproduction in ricefields. Some research results from the Asian tropics indicated that rice yields under a saturated soil condition throughout the growth period are either slightly lower, often not significantly, or equal to yields obtained under continuous shallow submergence conditions.

Undoubtedly, maintaining soil saturation will substantially save water due to a reduced S&P rate compared to the continuous submergence condition. On the other hand, it is well established that ricefield weeds are better controlled by increasing water depth in the field (Rao and Moody, 1986).

From a practical point of view, maintaining soil saturation, without allowing standing water or soil drying, is very difficult to achieve even when sufficient water is available to irrigate the field regularly. The precision levelling required to avoid pools of water in some parts of the field and soil drying at some other parts, either of which may negate the purpose of the practice, is very difficult to achieve by the farmers. It is not a question of one-time precision land levelling to be established on the farm, because a lot of soil movement takes place during the land preparation and puddling activities done in each rice growing season. Another practical problem associated with maintaining a saturated field is that controlled amounts of irrigation water have to be applied almost every day or alternate days to avoid drying up of the soil. If the soil is heavy-textured, as most rice soils are, cracks can develop even at nearly saturated soil-water conditions. Furthermore, this method will be impossible to implement in areas where water supply is not reliable.

* Irrigation system management interactions in vector control

Farm level water management manipulations can not be sustained unless the irrigation system is fully geared to support them. Thus, it is evident that the focus of attention for such purposes must not be given only on the farm or the farmer, but rather on the whole system in which the farms and the farmers are integral parts.

There are numerous places outside the paddy fields, but within the irrigation system, in which mosquitos of various species could breed and propagate. These include natural or man-made surface depressions, stagnant dead storage in canals, pools created by eroded canal sides, borrow pits, wheel ruts, choked drainage ditches, etc. Clearly, controlling water regimes in rice fields only, without adequate control of the breeding grounds outside farmer fields, will be of limited use. Sharma (1987) reported that the most commonly encountered mosquito breeding sites of malaria vectors in India are the irrigation or drainage channels rather than the rice fields **per se**. Thus, the need for an integrated programme of controlling the breeding grounds of the vector in all possible locations within the irrigation system can hardly be overemphasized.

Pesticide use and interaction with vectors

When the new package of technology containing the HYVs was ushered in, in the late 1960s and during the 1970s, there was a concurrent increase in the use of chemical insecticides for control of insect pests of rice. The wholesale adoption of insecticides was widely thought to be the best way to control insect pests. Use of insecticides was on the rise before the adoption of the HYVs. For example, there was a 500% increase in the use of insecticides in Central Luzon, which is the most intensively irrigated region in the Philippines, between 1966 and 1979 (Leovinsohn, 1987). This pattern was repeated in other parts of the world, not only on rice but other crops as well.

Besides creating outbreaks of previously unimportant pests, such as the brown planthopper, due to destruction of their natural enemies (Kenmore **et al.**, 1984), it is likely that insecticide overuse reduced natural predators and parasites of mosquito larvae. This, in turn, may have caused mosquito vectors to increase in some areas.

Although there is good plant resistance in the HYVs to a number of rice pests, pesticides are still overused. Fortunately, the integrated pest management approach, adopted by the IRRI and many national programmes, will help to ensure that sound strategies of pest control are developed with emphasis on conservation of natural enemies (predators, parasites and insect pathogens) and minimization of the dependence on petroleum-based insecticides.

Habitat changes

It has been suggested that rice fields which replace natural swamp vegetation result in lower populations of mosquitos such as **Mansonia** spp., because of habitat destruction. On the other hand, rice-field inhabiting species may be increased. Other speculations about the effect of reduced shading by the smaller canopy of the HYVs and the resulting response by the **Anopheles** spp. vectors are not substantiated by experimental data. It has been documented, however that **Mansonia** spp. populations favoured unirrigated areas while those of the **Anopheles gambiae** complex were denser in an irrigated area in Kenya (Surtees, 1970). Further, malaria transmission was higher near rice growing areas in the Ruzizi Valley in Burundi (Coosemans **et al.**, 1984).

It is difficult to generalize about the relationship between increased planting of HYVs (with concurrent increases in area under cultivation) and mosquito production. Relationships of this nature, if they exist, are likely to be location specific and must be examined on a case by case basis. It is clear, however, that environmental management is essential to optimize irrigation for agricultural production while minimizing the hazards associated with vector borne diseases.

Development trends and possibilities

It is difficult to predict the future status of development and use of the modern rice technology components which are related to the propagation or control of the mosquito vector. The reasons for this lie in the fact that numerous factors are responsible for the development of new technologies as well as their practical adoption in target areas. In this section we have attempted to speculate broadly on the prospects of these technologies, keeping in mind a 10-15 year time frame.

* HYVs of rice and their adoption

We should expect the development of more HYVs for irrigated environments, with more durable resistance in them against most major insects and disease organisms. These varieties therefore should require less applications of pesticides to achieve high yields. Advances in genetic engineering may make this goal possible by incorporating resistance characteristics from diverse known sources of rice varieties into the target rice line.

We should expect that very early maturing high yielding varieties, which would require 90-100 days to mature, will be available for the irrigated environments (Khush, 1984; Khush, 1987). These will enable farmers to increase their rice cropping intensity further.

It is expected that HYVs tolerant to water stress will be developed. But because of their lesser yield potentials than the irrigated rices, their adoption is likely to be limited mostly to unfavourable rainfed areas with water shortage during the growing season.

* Water management

Demands for irrigation water, particularly for dry season crops, will greatly increase as the pressure for more food grain production continues to grow. Water management techniques which will save water without sacrificing yields will be attractive to farmers, especially those who have to spend money to obtain water (such as the tubewell or pump supported farms). The alternate wetting and drying method of irrigation should be more appealing in that regard.

Irrigation development for more rice production will continue, but perhaps at a slower rate than the past two decades. However, this will mean that many rainfed areas considered unfavourable at the present time will have new irrigation facilities for intensive cropping.

The farm level and irrigation system level organization and discipline needed to make the alternate wetting and drying method of irrigation widely accepted is lacking at the present time. It seems unrealistic to expect that this situation will change drastically in the near future.

* Insecticide use

The Integrated Pest Management (IPM) approach to controlling insect pests, which could substantially reduce insecticide misuse and related development of resistance to insecticides by mosquitos, is not widely adopted yet. There are many social, cultural, and political reasons for this but in general IPM is more knowledge-based and requires trained farmers and extension personnel for proper implementation. Thus, it is likely that the current pattern of insecticide overuse on HYVs will continue for some time.

On a more positive note, there is evidence to suggest that massive farmer training programmes by agencies such as FAO, and national programmes are being embraced by some rice farmers who view the economic benefits of IPM as a logical alternative to calendar-based sprays of chemicals.

New and ecologically compatible methods of insect control may help to ensure that the overall pesticide load in the environment is lessened. For example, recently the gene responsible for the toxic substance produced by the insecticidal bacterium *Bacillus thuringiensis*, has been engineered into tobacco and tomato plants. Plans are being formulated to incorporate genes from these bacteria into rice. If successful, foliage-feeding insects might naturally be controlled due to the action of toxins produced by these plants.

Concluding remarks

Although most serious malaria-infested areas are not located where rice is grown, in spite of their very high densities of anopheline vectors (Najera, 1987), the threat of the spread of the disease with expansion of irrigation facilities is real. It is clear that no generalizations are possible, because the species-habitat relationships are rather complex and perhaps location-specific. Thus, research and monitoring is a continuing need in areas where the ecosystem is under a flux, as is the case where new rice irrigation facilities are developed.

In the context of future irrigation development schemes in tropical Africa, where mosquito-borne diseases are a very serious problem, extreme care must be taken to design

and implement appropriate measures for preventing the further spread and intensification of transmission of the disease and propagation of the vector. This is equally true for some tropical areas in Asia.

The strategy most likely to succeed in terms of checking transmission of the diseases is one that will address the problems of both vector propagation and man-vector contact. Rice producing areas are important on both accounts. Contributions from vector ecologists, epidemiologists, medical entomologists, rice pest control and irrigation water management specialists are needed for implementing an integrated control strategy for disease and vector propagation in target areas. Environmental management measures should form a major component of such an integrated strategy.

3. VECTOR-BORNE DISEASE HAZARDS IN CHANGING AGRICULTURAL PRACTICES RESULTING FROM OVERALL DEVELOPMENT IN AFRICA

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Introduction

Although the countries of Africa vary enormously in geography, climate and demographic aspects, they have a number of social and economic characteristics in common, i.e., large rural populations, large scale and unplanned rural-urban migration, rapid urban growth and limited resources. The agricultural practices in Africa are highly diverse, ranging from peasant and tenant small plots (shifting cultivation through to wet rice culture) to export crops. Shifting cultivation is one farming system indigenous to tropical Africa. Although it is stable at low population densities, it becomes less stable at high densities. Over time, it has led to forest destruction and soil erosion and degradation (Okigbo, 1983).

Even though much of Africa is favoured with adequate rainfall, abundant sunshine and tillable soils, vast areas have been little used. Associated with this, a dominant feature of agriculture in Africa has been its low productivity which is manifested in the cumulative discrepancy between African production rates and rates achieved elsewhere in the world (Hyden, 1984). While the world's average output of cereals is about 2000 kilogrammes per hectare, Africa's average rarely reaches that figure (with the exception of Egypt where yields are as high) (FAO, 1986a). For roots and tubers, Africa's average of approximately 7 tons per hectare is well below the world's average of 11 tons per hectare. The recurrent food crises in Africa also demonstrate the point that efforts to achieve increased agricultural productivity have been far less successful than had been envisaged. At the same time, the impoverished families had to depend on fragile agricultural systems for their subsistence and for a large portion of their cash earnings to cope with the social and economic pressures resulting from high birth rates and high mortality and morbidity resulting from a large array of diseases.

Importance of vector-borne diseases in Africa

The health situation in Africa is primarily characterised by its precariousness, a direct and close relationship between certain illnesses and the environment, as well as the strong links between disease vector problems and particular ecological zones. Vector-borne diseases remain among the most important public health problems in Africa. In fact, in Africa, the risk from vectors is formidable in that the vectors that cause diseases grow freely and easily. Moreover, the general lack of sanitation and the behaviour patterns of the population combine to provide favourable conditions for vector-borne disease transmission.

These diseases cause high rates of mortality and morbidity. The most important of these diseases were reviewed at a meeting in Brazzaville in 1985 (WHO, 1985). They were identified to be: malaria, onchocerciasis, trypanosomiasis, schistosomiasis,

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lymphatic filariasis, dracunculiasis, yellow fever, louse-borne typhus, plague and other arbovirus diseases. Some of these may be prevalent in limited parts of Africa only.

Malaria is endemic in 90% of the African region and is one of the most important causes of mortality and morbidity in infants and young children. Reliable health statistics are lacking in most African countries as a rule, but it has been estimated that about half of all the children under the age of three are infected. Although much is being done in various parts of the continent to reduce the risk from malaria it remains the major public health problem of Africa.

Onchocerciasis has been reported from 28 countries in Africa and it is estimated that about 18 million people are infected with the disease. Geographically, the disease extends from latitude 2°N to latitude 15°N from Senegal in the West to Ethiopia in the East. South of this belt, the disease appears in scattered foci to latitude 17°S.

On account of the blindness and the general debility the disease causes, a control programme was mounted in West Africa. After 12 years of larviciding, a great reduction in the numbers of the vectors and in the prevalence of the parasitic worm **Onchocerca volvulus** was achieved. In addition, very few of the children born since control started have become infected (WHO, 1985).

Trypanosomiasis. African trypanosomiasis was perhaps one of the major factors in the depopulation of large tracts of Africa (Molyneux, 1986). The disease is caused by **Trypanosoma brucei gambiense** in West Africa and **Trypanosoma brucei rhodesiensis** in East Africa ranging from Botswana to Ethiopia. Increasing numbers of cases of the disease have been recorded in Ivory Coast, Gabon, Kenya, Cameroons, Nigeria, Zaire, Ethiopia, Sudan and Tanzania.

Schistosomiasis affects as many as 50 million people living in the African region south of the Sahara, and about 100 million are estimated to be exposed to the threat of infection (WHO, 1985). The parasite **Schistosoma haemotobium** is widely distributed, while **S. mansoni** is limited to parts only of nearly all countries except Lesotho. In many countries, the heavy infections appear to be increasingly associated with prolonged periods of contact with water over long periods of time especially in irrigation projects.

Lymphatic filariasis is widespread in Africa. The disease is caused by **Wuchereria bancrofti.** Some of the vectors are the same as those of malaria, i.e., **Anopheles gambiae** s.l. and **A. funestus**, but also species belonging to the genera **Culex** can transmit the parasite. In certain parts of the East coast of Africa, **Culex quinquefasciatus** is in fact the major vector of the disease.

Yellow fever. Outbreaks occurred in Ivory Coast in 1982, Ghana and Burkina Faso in 1983 and Nigeria in 1986 and 1987. The presence of the virus has occurred in more or less severe epidemic outbreaks. In Ivory Coast, immunization and control of **Aedes aegypti** mosquitos by chemical larviciding, applying temephos in drinking water containers, rapidly stopped the epidemic.

Louse-borne typhus due to **Rickettsia prowazcki** is still an important problem in the highlands of Central and West Africa where it has been recorded in Chad, Botswana, Ethiopia, Gabon, Niger, Nigeria, Uganda and Zambia.

Plague is firmly established in its main natural foci around Lakes Albert and Edward in Zaire, in Tanzania and in southern Africa and Madagascar.

Leishmaniasis. Cases of visceral leishmaniasis have been reported for some time now in Algeria, Sudan, Ethiopia and Kenya. In its cutaneous form, it is prevalent in Algeria, the Sahelian countries and Sudan.

Dracunculiasis is still prevalent throughout the sub-Saharan region of Africa, especially in areas which are short of safe drinking water.

Dengue has been identified in East Africa, Burkina Faso and Ivory Coast. It is transmitted by **Aedes aegypti**. In Africa, this vector seems to be firmly established where minimum temperatures are above 10°C.

The above list shows that in most parts of Africa, whether in farming or any other type of industry, disease vectors constitute a vital component of the environment. Since the failure to incorporate the major components of the environment in decision-making affecting development often leads to failure of projects, higher priority must be given to the health implications of any development if it is to be implemented successfully.

Agriculture in transition

As has been pointed out, agricultural productivity all over Africa is low and, with the exception of the Onchocerciasis Control Programme (OCP) areas of West Africa where definite progress has been made, the occurrence of vector-borne diseases seems to be on the increase. At the same time, nutritional problems are not showing any signs of abatement in the region. Apart from the overt diseases like kwashiorkor, marginal nutrition contributes to the high death toll by predisposing to infection. Infection itself further worsens the nutritional state of the victims thus creating a vicious cycle that takes a heavy toll of lives. Living standards of the people seem to be falling as a result of explosive population growth.

The first priority of agriculture is to raise productivity of presently cultivated land on a sustainable basis. Raising the productivity of the land will depend largely on more and better use of inputs combined with improved husbandry. FAO (1986b) has shown that the constraints to raising crop productivity which have to be overcome in Africa are many and have been identified as:

i. the diversity and complexity of prevailing farming systems;

ii. restricted use of external inputs and dependence on fallow for maintaining soil fertility and weed control;

iii. inadequate integration of crop and livestock production;

iv. orientation of farming to subsistence production;

v. predominance of small farms dependent on family manual labour; and

vi. dependence of agriculture on rainfall

It is now well known that shifting cultivation cannot support a high density of people and that the agricultural system that developed in the Americas, the Near East and China and which supports the people there is through irrigation and drainage. Experience in tropical Asia also shows that the best system of arable cropping in a warm climate is the concentration of production in the relatively fertile hydromorphic valley bottoms. That is where the most fertile lands occur and often irrigation is practicable. This means that upland cultivation which has been the main emphasis in Africa, and involves a much greater disturbance of a tropical ecosystem, must be replaced by crops whose effect on the soil is similar to that of the forest or bush vegetation (Ruthenberg, 1980).

Juo and Lowe (1986) have shown that tropical sub-saharan Africa has a total of 200 x 10^6 hectares of wetlands that exist in the form of small inland valleys, river flood plains, inland basins and coastal wetlands. At present, only an estimated 3 x 10^6 hectares of these lands is used for cultivation of rainfed lowland rice and for irrigated paddies (1.5% of the total area). It is obvious therefore that the utilisation of these wetlands for rice cultivation holds a good prospect for raising agricultural production and meeting food demands in Africa.

Des Bouvrie and Rydzewski (1977), have described additional advantages of introducing irrigation and drainage into different climate and vegetation zonesof Africa, as follows:

(a) in arid areas to provide opportunity for settled agriculture;

(b) in semi-arid areas to permit intensification of cropping, to achieve higher yields and greater diversification of crops;

(c) in areas where the amount and distribution of rainfall is unpredictable to minimise risk of crop failure or maintain a high level of yield;

(d) in areas of excessive moisture to reduce the soil moisture level to that required for optimum growth; and in addition

(e) to meet special water requirements of cash crops such as rice or sugar cane for which climate but not field water requirement is suitable.

Some 54% of the total land surface of Africa is covered by arid, semi-arid and desert areas (FAO, 1977, 1978). This large ratio of dry area calls for a far greater effort with irrigation than has been generally realised. Taken with the knowledge that the wetlands of sub-saharan Africa have a growing period of 150 days or more (FAO, 1978), it becomes obvious that agriculture and especially wet rice cultivation provide an option for the future development of agriculture in Africa. The traditional forms of agriculture which exist today must be seen as transition stages for tomorrow's efforts.

Discussion and Conclusion

Africa has an estimated 9.5 x 10^6 hectares of irrigation of which 6.1 x 10^6 hectares is modern irrigation mostly of public schemes and 3.4 x 10^6 hectares of small scale, traditional, flood, swamp and low lift irrigation schemes. Egypt, the Maghreb countries and the Sudan account for 82% of modern irrigation in Africa (FAO, 1986b).

A review of the existing irrigation and water impoundment projects in developing countries shows that intensification of development through irrigation and water resources project expansion coincided with the deterioration of the health of the people living and working on the schemes. As the natural fast water habitats for **Simulium** larvae have been submerged and destroyed during dam construction, the possibilities for the breeding of snail vectors of schistosomes and anopheline and other mosquito vectors and the multiplication of disease vectors around the newly-formed reservoir have been significantly increased (Lowe McConnel, 1966; Obeng, 1969; Ackermann **et al.**, 1973). The reduction in water quality may also introduce increased risks of certain other insect vectors as can effluents from domestic settlements associated with industrial development (PEEM, 1983). In those areas where a large number of small scale water developments have been erected, disease vector problems especially schistosomiasis and malaria have also increased. For example, Wijeyaratne (1982) found that a small earth dam in northern Nigeria increased the incidence of schistosomiasis, malaria and

bancroftian filariasis vectors in the study area. A similar study by Imevbore **et al.**, (1986) found that several small scale informal water schemes in Kano State, Nigeria, were creating serious schistosomiasis and dracunculiasis problems.

On the other hand, McJunkin (1965) has pointed out that although there are obvious links between schistosomiasis and irrigation, the link is most strongly associated wtih defective and inefficient irrigation, poor land preparation and lack of free drainage rather than with irrigation **per se**. "Schistosomiasis engineering in considerable degree is just good irrigation practice" and Kay and Carter (1984) have shown that it is in maintaining good irrigation practice that many developing countries often lack the skills and the equipment. There is also evidence that when deliberate measures are taken to avert adverse consequences of health at the planning, design and operational stages, the health problems can be curtailed. Mott (1984) also pointed out that, based on sound epidemiological principles, the reduction in the prevalence and severity of schistosomiasis is a feasible objective which is within the scope of every endemic country in Africa.

The option before Africa is therefore clear: to take deliberate measures on environmental management techniques to implement irrigation and water resource development projects in such a way that adverse health effects are minimised. As a way of according high priority to health considerations in all water development projects, PEEM (1981) has suggested that in examining water development projects, not only the possible adverse consequences for health but also the opportunities for improving health should be considered. This would mean undertaking not just health impact but health opportunity assessment. In addition, both pre- and post-construction surveys are vital to ensure that the health hazards of a project do not outweigh the expected benefits accruing from it. For Africa, the effort to combat vector-borne diseases should not be considered only as a small part of the environment of development but as a vital component of total socio-economic programming for development.

4. THE HISTORY OF IRRIGATION DEVELOPMENT IN KENYA AND THE ASSOCIATED SPREAD OF SCHISTOSOMIASIS

P.G. Waiyaki[1]

Introduction

Schistosomiasis is a major and increasing health problem in the irrigated areas in Africa. In Kenya, its distribution is as follows:

a) the coastal region in which urinary schistosomiasis predominates but with intestinal schistosomiasis also occurring in the Taita-Taveta District

b) the central region in which mainly intestinal schistosomiasis occurs but with some urinary schistosomiasis, and

c) the Lake Victoria region in which both schistosomiases are found (Highton, 1974).

It is estimated that 10% of the Kenya population suffers from schistosomiasis (Warren, 1979). This, coupled with the rapid population growth rate which now stands at 3.8%, suggests that the increasing population density may lead to intense transmission. The 1979 national census showed a population in excess of 16.5 million. Approximately 52% were in the 5 -14 year age group. By 1988 it is projected that the population will be in excess of 23 million and by the year 2000 the population will be 38.5 million, with roughly 52% of the population being in the 0 - 14 year age group (Jordan, 1985). Assuming that there is no change in the transmission pattern, by then nearly 3.9 million Kenyans will suffer from schistosomiasis.

Kenya's economic progress will for the foreseeable future largely depend on agricultural development. To this end it has been government policy to bring into productivity large tracts of idle land in Nyanza, North-Eastern and Rift Valley Provinces, through intensive irrigation and reclamation. At least 200 000 ha of arid and semi-arid land can be converted to perennial irrigation in order to increase food production and also to release population pressure. While the potential benefits for irrigation are widely recognized, health problems which arise are also appreciated and programmes have been mounted in the planning stages to assess health hazards in areas where schistosomiasis is endemic. However no legislation exists to enforce this.

Major Irrigation Schemes in Kenya

The most economically important irrigation schemes are Mwea, Hola, Bura, West Kano, and Ahero. They are managed by the National Irrigation Board (NIB). This is a quasi-governmental body established in 1966 with the mandates for developing, constructing and operating irrigation schemes in the country. In the NIB schemes reside 6 000 farmers and their families, making a total population of 48 000 people. The irrigation scheme at Taita-Taveta is controlled by the Agriculture Department in the Ministry of Agriculture.

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MWEA IRRIGATION SCHEME

The Mwea Irrigation Scheme was developed in 1952. The scheme is located on the upper catchment of the Tana River Basin near the foothills of Mount Kenya, at a distance of 100 km north-east of Nairobi. This is principally a rice growing scheme and produces 90% of all rice cultivated in Kenya. The scheme consists of 6 000 ha but work is in progress to extend it by another 1 500 ha. There are 3 000 plot holders living in 35 villages with a total population of 35 000. Each tenant is allocated a two hectare plot. Housing is provided, latrines are dug by the tenants, water (untreated) and washing slabs are provided by the NIB.

Schistosomiasis prevalence rates

Before the scheme was developed, schistosomiasis had not been reported in the area and the first case was recorded in 1959. In 1966, 1 875 persons were examined and 218 were found to harbour the disease. This gave a prevalence rate of 12.5%. In 1971, 2 978 people were examined and 24.4% were found to be infected. In 1972, when there was temporary cessation in mollusciciding, the prevalence rate increased considerably to 40%. Figures reported by the NIB in 1982 indicate that the prevalence rate of schistosomiasis caused by **Schistosoma mansoni** stood at 25%.

Snail survey, control and research

Snail surveillance and mollusciciding have been maintained in the scheme, albeit not always on a continuous basis. The entire irrigation system is treated three times a year using 70 W.P. Bayluscide^{R} (niclosamide). At present it is unlikely that complete eradication of the snails can be accomplished because of the presence of overgrown habitats and seepages from the canals and drains. This creates small swamps which are ideal snail nurseries and leads to inadequate penetration of the molluscicide into the breeding sites.

At present there is a pilot schistosomiasis control project under the auspices of Kenya Medical Research Institute and the Canadian International Development Research Centre. The objectives of the project are to evaluate the effects of piped water supply, sanitary improvement and community education and participation on transmission of the disease. The project is based on two villages with a population of 2 000. At present **S. mansoni** infection rates range between 60% and 70% in the study sites.

AHERO IRRIGATION SCHEME

The 840 ha. Ahero rice irrigation scheme was established in 1968 as a pilot project managed by the NIB. The scheme is located within the Kano plains in the western part of Kenya, 40 km east of Kisumu town and at an altitude of 1220 meters. The scheme was established:

i) to provide experience in the best methods for tackling development in the region and

ii) to demonstrate to the local people, (who tenanted the scheme), the advantages of new approaches in land utilisation as compared to traditional ones.

Prevalence of schistosomiasis in the plains and adjacent areas

Kinoti (1971a) studied the epidemiology of **S. haematobium** infection in the area and found a low prevalence rate of 3.5% in 1 708 school children. He attributed this to the striking absence of **Bulinus nasutus** and **Bulinus africanus**, the principal intermediate snail hosts. However, in other areas adjacent to the plains, high **S. haematobium** infection rates in 774 children studied by Kinoti were obtained. In a

related study, Kinoti (1971b) showed that **S. mansoni** infection was also low (approximately 4.2%) in 740 school children. Similarly in the neighbouring Nyakach District, out of 457 school children studied, only 4.7% were infected. No **Biomphalaria pfeifferi** were found in Kinoti's (1971b) survey, but he did caution that **B. pfeifferi** had been collected on three different previous occasions and, if the host was introduced into the scheme, it was likely to play an important vector role. Brown (1975) extended the studies by Kinoti. He investigated the distribution of intermediate hosts on the Kano plain. His findings showed that **Biomphalaria** and **Bulinus** species, the intermediate hosts for **S. mansoni** and **S. haematobium**, respectively, were discontinuously distributed and their absence from extensive areas of the Kano plains provided an explanation for the low prevalence of schistosomiasis in these areas.

Mollusciciding and snail control

Choudry (1975) evaluated the results of a five year snail control programme in the scheme. The programme was initiated at the inception of the scheme in anticipation of an increase in the transmission of schistosomiases. During the five years of the programme, N-tritylmorpholine (Frescon^{R}) was routinely applied to the irrigation system and the irrigation canals remained free of snail intermediate hosts. The average annual cost was relatively small - US$ 1.58 per ha. (0.78% of the total cost).

In 1982 (NIB Report) there was a prevalence of 0.8% intestinal schistosomiasis in the scheme and to date (Ouma, J.H., personal communication, 1987) the scheme has remained relatively free of vector snails and there is no evidence that the creation of the scheme has led to the limited transmission reported. **B. pfeifferi** has occasionally been found in the canals and it should be viewed as a potential colonist and host for **S. mansoni** in the scheme.

BURA IRRIGATION SCHEME

The Bura irrigation scheme is situated in the Tana River Basin in North Eastern Province. The scheme is being developed in stages and the first stage covers an area of 6 700 ha. Cotton, groundnuts and maize are grown. In the planning stages, the scheme was envisaged to have at least 23 villages with 2 500 tenants and their families. Each house was provided with water and latrine. Two showers were to be constructed for every 12 houses (in 1985, not provided yet). Further, each person was entitled to 100 litres of water per day (MacDonald, 1977). Before the construction began, prevalent disease problems were investigated with a view to predicting possible increase or introduction of a disease into the area.

Tenants came from all parts of Kenya and particularly from the coastal region where urinary schistosomiasis predominates. On arrival at the scheme, each tenant was examined and those found infected were treated as necessary. Currently, there are 2 000 tenant farmers and 13 000 members of their families living in 10 villages. The projected age distribution shows that by 1988, 29% of the population will be 5-14 years old. Because of the known frequent contact with water in this age group, transmission of schistosomiasis is likely to rise.

HOLA IRRIGATION SCHEME

This is a cotton producing scheme situated in the lower Tana River Basin. It was established in the 1950s in an area where urinary schistosomiasis is endemic. Derryberry **et al.** (1967) in 1965 recorded 70% **S. haematobium** infection in Pokomo children of school age. In 1974 Highton (cited in Choudry, 1975) found 100% infection among residents of Hola. More recently (Magambo, 1982) reported infection rates of 90% in Pokomo and Orma children in the 5-14 year age group. Despite a reasonably sophisticated environmental sanitation system and a regular mollusciciding programme, there is a high prevalence of

infection. A survey done in 1977 by the Division of Vector Borne Diseases of the Ministry of Health showed a prevalence of 77% of **S. haematobium** infection. **B. globosus** snails are widely distributed in the irrigation scheme. Although the snail hosts of **S. mansoni** do not occur at the scheme or in areas adjacent to it, the change in the environment following irrigation may create conditions favourable for **B. pfeifferi** as happened at Mwea (Choudry, 1974).

WEST KANO IRRIGATION SCHEME

This is a 1 000 ha rice producing scheme situated in Kisumu District on the shore of Lake Victoria. **S. mansoni** infection is common along the edge of the scheme. Choudry (1975) reported a prevalence infection rate of 62% in school children. Available data indicate that in 1982 the transmission rate of **S. mansoni** was 1.7%. **B. sudanica** is common in swamps around the scheme and **B. pfeifferi** and **B. africanus** snail hosts are also present. **S. haematobium** is not common in the West Kano area.

TAVETA IRRIGATION SCHEME

The Ministry of Agriculture operates an irrigation scheme at Taita-Taveta District. The scheme was started in 1928 and covers more than 1 000 ha with an irrigation potential of about 4000 ha. There is a settled population of 800 families. Approximately 19 000 people live in villages adjacent to the scheme. Six thousand live in two villages on the scheme. Surveys on the two villages showed high prevalence rates of 68% in one village and of 70% in the other. In both villages the urinary schistosomiasis prevalence peaks were in the 5-14 year old age group. On the other hand the peak for **S. mansoni** infection was in the 30-39 year age group. This indicated that schistosomiasis in the latter groups may be an occupational disease. Transmission of **S. mansoni** and **S. haematobium** occurs throughout the year.

Naturally infected **B. pfeifferi** are found in the irrigation canals and also in River Lumi, the source of the water used in the scheme. **B. globosus**, **B. tropicus** and **B. forskalii** have also been found in and around the scheme.

Conclusion

In this paper certain factors relating to the spread of schistosomiasis as a result of the development of irrigation schemes are evident. While snail control programmes in the various schemes have been in force, there are times when they are either temporarily discontinued or not periodically reviewed for their effectiveness. Inadequate supplies of water and sanitation, siting of village settlements, lack of periodic assessment for effectiveness of drug therapy, weakness of supporting laboratory services, limited ecological surveillance of vector snails and other constraints have created a somewhat unclear picture of the current status of schistosomiasis in the schemes. It is, however, quite clear that unless effective control programmes are put into effect, the transmission of schistosomiasis in the irrigation schemes is apt to increase. Vector snails, their necessary ecological habitats and other factors are all available for such an eventuality.

5. THE EFFECT OF WATER DEVELOPMENT PROGRAMMES ON MALARIA AND MALARIA VECTORS IN TURKEY

N.G. Gratz[1]

Malaria is known to have been endemic in Turkey for a very long period of time. Little information, however, was available even as to the proportion of the different species of parasites until the early 1950s. At that time DDT applications were started in selected areas of the country and a national malaria eradication programme began in 1957. At its peak this programme was reported to have covered a population of some 30 million people. The annual parasite index (API) per 100 000 was reported as 126 in 1957/1958 and by the early 1970s this had been reduced to almost 3 per 100 000.

By that time, the Government of Turkey felt that it could no longer sustain the expenditure of such a large proportion of its health resources on malaria eradication/control activities and these services were considerably reduced. Unfortunately the remaining malaria control activities were not effectively incorporated into the country's public health network or the developing primary health care services, either from a viewpoint of surveillance or from that of control, and therefore the remaining malaria control services were unable to detect in time, or effectively deal with, a severe crisis which developed in the late 1970s.

In the mid-1970s, a large irrigation project including a dam and an extensive network of irrigation channels was implemented in southern Turkey, creating a very large irrigated area on the Çukurova plain including the immediate area and surroundings of Adana. This greatly increased agricultural development along with a subsequent industrial expansion, and encouraged a substantial migration to the area, mainly from eastern Turkey where malaria was still endemic. The number of migrants entering the area reached 280 000 in 1980 and, while the migration was seasonal at first, an increasing proportion of the migrants remained in the area for longer periods and some became settlers.

As a result of the malaria eradication/control programme in the country, malaria in Turkey had, before the Çukurova outbreak, been brought to a low point of 1 400 reported cases of which a mere 49 were from the area of Adana. However, with the dispersion of the specialized surveillance teams following the cutback in malaria control activities, the health services failed to detect and respond in time to a continuing increase in cases of malaria among the migrants and indigenous inhabitants in the Çukurova plain, an area where **Anopheles sacharovi** populations were vastly increasing as a result of a combination of greatly extended irrigation and poor drainage. This culminated in a serious epidemic outbreak of the disease in 1977 in which year no less than 115 512 cases were reported around Adana and the API rose to about 278 cases per 100 000. Fortunately, all of these cases were caused by **Plasmodium vivax**.

The problem posed by the epidemic was further compounded by the development of resistance to the organochlorine insecticides in the **A. sacharovi** populations and, in addition, a high rate of spray refusals among the inhabitants of the endemic area, who did not accept continued malathion spraying due to their objection against the strong odour of this insecticide. Concerted control efforts including mass drug distribution, larviciding, the distribution of larvivorous fish and various spray measures using alternative OP residuals such as pirimiphos methyl, reduced the API to 67/100 000 and by

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1978 the number of cases fell to 70 468 and in 1979 to 29 234. Onori and Grab (1980) estimated that if no remedial measures had been taken, the number of malaria cases would probably have risen to more than 250 000 in 1978.

In the early 1980s rates of refusal of house spraying rose and the number of malaria cases reported from Turkey increased to 62 038 cases in 1982 and 66 681 cases in 1983. Of these, 18 537 cases and 35 919, respectively, were from the Adana area alone. In 1984 the malaria situation in Turkey started to improve but this improvement was more marked in eastern Anatolia than in the Çukurova plain. By 1984, 55 382 cases and in 1985 some 24 617 cases of malaria were reported from the entire country.

It is regrettable that no information is available on the cost of this serious outbreak of malaria to the health services of the country or the economic costs in terms of lost employment. In any event, if the costs of the large quantities of additional insecticides and application equipment, drugs and labour involved in their employment are considered, the real cost of the outbreak must have been very considerable indeed and its after effects are still being felt.

As recently as 1984, discussions with the irrigation and drainage authorities in the area revealed that there were no plans to improve the drainage system in the area and to do so was considered to be excessively costly. It must also be emphasized that such drainage improvements are beyond the responsibility, competence or control of the malaria service or health service in general in Turkey.

There are probably few areas where the cause and effect between agricultural development and increased malaria can be so readily seen as in the Çukurova plain in Turkey. The sequence of construction of a large irrigation system with very inadequate, or, in many of the areas, no provision for drainage, the increased agricultural activities requiring more and more irrigation and the vast increase in population densities of the main vector in the area, **A. sacharovi**, combined with an influx of migrants, (most of them arriving from a malaria endemic area) , inadequate surveillance activities and the failure to institute satisfactory control measures in good time led to the epidemic of 1977. While this epidemic was finally arrested, the basic corrections to the drainage systems are yet to be made and the cost of doing so mounts every year.

Water for irrigation on the Çukurova plain is taken from holding reservoirs in large canals over 15 meters wide. The water in these canals moves very swiftly and there is no mosquito breeding in them. Water is then fed into the farming areas by smaller, concrete-lined secondary canals and finally to the individual farming areas by an extensive network of elevated asbestos/concrete U-shaped channels some 1 meter wide, called "caneletti". Water is taken from these by the farmers through plastic syphons. There are some 600 km of secondary canals and 1587 km of tertiary canals.

There is virtually no breeding in any of the canals due to the rapid flow of water through them but there is a considerable leakage and spill-over from the tertiary canals and larvae are frequently found in the pools that gather beneath these channels. The greatest amount of breeding is, without question, in the ditches which receive the run-off or excessive irrigation water. These may vary in size from half a meter or less to 3 meters in width and are of varying and irregular depth. Very little attention is paid to the cleaning of these ditches carrying away the run-off water and most are choked with weeds and become ideal larval habitats for the vector of malaria. Furthermore, as the run-off water drains into the low-lying coastal areas it spreads out and forms large areas of marshes which are also major sources of anopheline breeding.

It should be kept in mind that a new dam and irrigation system is being constructed in the Uria area to the east of the Çukurova plain. This area is already endemic for malaria and will, no doubt, attract very considerable numbers of migrant workers when agricultural activities are intensified in the area. Whether or not the lessons available to be learned from the experience of the Çukurova plain will be applied remains to be seen.

6. MALARIA RISKS INVOLVED IN SLASH AND BURN AGRICULTURE IN **A. DIRUS** INFESTED FORESTS IN THAILAND

Santasiri Sornmani[1]

Slash and burn agriculture in the forest areas of Thailand

In every country where there is population growth there is a need to increase the food supply accordingly. This need is highest in developing countries where the population increases rapidly, while, at the same time, economic growth from natural resources is limited. To solve this problem, the developing countries, such as Thailand, usually have to expand and intensify their agricultural activities. For decades, the increase of cultivated land began with the penetration into forest areas. People slashed and burned the trees and shrubs and turned the forest into bare land for agricultural activities. The forest deterioration in Thailand is a big and long standing problem. When the data from LANDSAT imagery taken in 1982 were compared with aerial photographs taken in 1961, they showed that in 21 years the forest had deteriorated at the rate of 5 572 km^2 per year. In 1985, only 29% or 149 053 km^2 of the country's land area remained as forest (Table 1). The deterioration of forest is nevertheless retarded because by law most of the areas have been declared forest reserves which are illegal to trespass or occupy. The process of occupying the land therefore has to be gradual, beginning with cutting down big trees and burning them for charcoal, and followed by burning of all shrubs and landlevelling. Such action is usually done by the indigenous people on a small scale.

The land is then privately sold to richer groups who, after a period of buying plots, can own a large piece of land. This procedure is common in the Central and Eastern parts of the country. What is left is a large prairie at foothill or forest fringe. Examples are the tapioca plantation in Cholburi Province or the sugarcane plantation in Kanchanaburi. Another type of forest deterioration occurs in the north, particularly on the high mountains. Here, the hill tribes cut down and burn the trees to grow opium. When the land becomes less fertile they move and repeat this process on other mountains.

Forests in Thailand have been recognized as malarious areas for decades. Because of the monsoon, the forest was thick and had a closed cover, and served as the habitat of mosquito vectors. Kanchanaburi, for example, in the past had the reputation as the land of thick, evergreen forest with a large population of wildlife. Even today, the forest is still considered as the largest wildlife reserve area of the country. In 1961, 91.3% of the territory of Kanchanaburi was forested and it was reputed as the province of cerebral malaria. Another example is Cholburi Province on the eastern coast of the Gulf of Thailand. In 1961, the forest occupied 49.2% of Cholburi's territory. This province was also recognized as a highly endemic area of malaria. At present, forests in these two provinces have been trespassed and turned into agricultural land. In 1982, only 53.7% of Kanchanaburi and 5.9% of Cholburi remained as forested areas (Klamkamsorn and Charuppat, 1983). During this period the endemicity of malaria also decreased in these provinces.

High incidences gradually decreased and in 1986 the Annual Parasite Index (API) in Kanchanaburi was only 26.8 and in Cholburi 8.1. The change in risk of malaria in these provinces may not be entirely due to forest penetration and change into

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Table 1. Forest Deterioration in Thailand during 21 years (1961-1982)

Region	Forest area km^2 1961	Forest area km^2 1982	Total Deterioration km^2	Average per year km^2
North	116 275	87 756	28 519	1 358
East	21 163	8 000	13 163	626
Northeast	70 904	25 866	45 018	2 143
Central	35 660	18 516	17 144	816
South	29 626	16 442	13 184	627
Total	273 628	156 600	117 028	5 572

Source: Forest situation of Thailand in the past 21 years, Sept. 1983, Remote Sensing and Forest Mapping Sub-Division, Royal Forest Department.

agricultural land. But certainly, this environmental change has an impact on the habitats of mosquito vectors and eventually on the transmission of malaria. In some areas, malaria prevalence decreased or disappeared, in others transmission was low but persistent. The malaria risk in relation to the slash and burn agriculture area in Thailand, can therefore vary from little or no-risk to low but persistent, depending on the nature of agriculture, the human behaviour, and the vector mosquito in a particular area.

Anopheles dirus, the jungle breeder in Thailand

A. dirus has been considered to be the mosquito vector responsible for the transmission of malaria in the forest of Thailand since 1956. The vector was called **A. balabacensis** until 1984 when its nomenclature was changed to **A. dirus** as a result of cytogenetic studies. Based on metaphase chromosomes using the Giemsa and Hoechst 33258 techniques, four sibling species were identified as **A. dirus** A, B, C and D (Baimai **et al.**, 1984). Since **A. balabacensis** in Thailand was renamed as **A. dirus** only a few years ago, information on this vector has to be based on the past studies of **A. balabacensis.**

A. dirus is spread all over Thailand. It seems, however, that there are distinctive distribution patterns among the sibling species. Species A is common in Central and northern Thailand, while species B is found in the South and species C is only found in Kanchanaburi. All **A. dirus** are good vectors of human malaria, however species A seems to be more susceptible to **P. vivax** and the parasite develops better in this vector (Andre **et al.**, unpublished as quoted by Baimai 1984). Nevertheless, adequate information on the differences of habitat requirements, biting behaviour, seasonality and other characteristics of the sibling species needs to be obtained and confirmed by further studies.

In general, **A. dirus** in Thailand breeds all year round, but the population density is highest during the rainy season. In the dry season the density is markedly decreased to almost scarce due to the lack of breeding places. The presence of this anopheline is always associated with dense forest or forest fringes with favourable humidity and shade. They lay eggs in small pools, pits from gem mining, moist sand, human and animal foot prints and moist clay. The breeding places have to be mostly under heavy shade. **A. dirus** feeds largely on man although it also feeds on monkeys or cattle. They are late biters, indoor as well as outdoor, but rest outside the house. In the day-time they have been found to rest in rock holes, thick grass, shrubs etc., all these places being dark, humid and shaded (Scanlon and Sandhinand, 1965, Wilkinson **et al.**, 1978). When conventional insecticides were tested no resistance was found in this group of anophelines. However, it was observed that the DDT residual spraying encouraged the frequency of outdoor biting as compared to indoor biting (Ismail and Pinichpongse, 1980).

The malaria risk in slash and burn agriculture in **A. dirus** infested forest in Thailand

The relationship of malaria and **A. dirus** infested forest is very interesting since it poses a serious problem in the control of malaria in Thailand. However, to obtain good scientific evidence to demonstrate the impact of slash and burn agriculture on malaria transmission influenced by **A. dirus** is difficult, since information is scarce and most epidemiological data have not been longitudinally recorded. In addition, being a jungle breeder, study of **A. dirus** was and still is very difficult and expensive.

In general, it can be said that the forest area in Thailand was formerly endemic for malaria and that the principal vector was **A. dirus.** Once the forest was penetrated, the trees were cut down and shrubs burned to clear land for agricultural activities. The changed pattern of malaria transmission can be seen as follows:

i) low or no transmission
ii) low but persistent transmission

As mentioned above, factors contributing to malaria risk in slash and burn areas are the nature of agricultural activity, human behaviour and the vector mosquito. Two study cases will be cited here to demonstrate the different malaria risks in slash and burn agriculture in **A. dirus** infested forests in Thailand.

The Tapioca Plantation in Cholburi - Low malaria risk in a slash and burn agriculture area

Cholburi is a province located on the eastern coast of the Gulf of Thailand. It is about 120 km from Bangkok and has a total surface area of 4 363 km^2. In 1961, 49.16% of the province consisted of forested areas. The forest was of the tropical evergreen type with plenty of hardwood. At that time, timber industry was the major source of income of this province. The forest of Cholburi was considered as a hyperendemic malaria area. The main species was **P. falciparum** and the principal vector was **A. balabacensis** (= **A. dirus**). Because of its high density, in 1963 a study by SEATO Medical Research Laboratory was made on the distribution and biology of this vector at Khao Mai Kaeo, Bang Lamung District, Cholburi Province (Scalon and Sandhinand, 1965). With the advance in agriculture and the timber industry the low-land forest had been

extensively cut. A large part of forest area was replaced by tapioca plantations. The area was hyperendemic with falciparum malaria with a sporozoite rate of 8.7%. The spleen rate was 66.6% in children under one year old. The study on bionomics of **A. dirus** indicated that the conventional method of control of malaria would be extremely difficult in this area since, after biting, the female could avoid the DDT sprayed wall of the house by resting outside. The breeding places of this vector were also found to be diffuse in distribution. The common places were rock pools, human or animal footprints, pits, and moist sand. Nearly all the breeding places were under heavy shadow and the larger concentrations were found in fairly thin forest or along the forest margins (Scanlon and Sandhinand, 1965). In addition, the drug resistant strain of **P. falciparum** was also discovered. In the following years forest penetration of Cholburi Province (including Khao Mai Kaeo) took place to such an extent that, through slash and burn activity, the majority of forest was turned into one of the largest areas of tapioca plantation in Thailand. The forest area was reduced from 49.16% in 1961 to 14.6% in 1976 and 5.94% in 1985. At the same time the prevalence of malaria and the **A. dirus** population in this province also decreased. The slash and burn activity can not solely be credited with the decrease in malaria transmission of Cholburi Province, the control programme which was initiated in 1964 has played a major role, too.

The type of plant cultivated in the area after the land has been cleared is also important. In the case of Cholburi Province, where a large part of the forest was turned into tapioca plantations, the malaria risk was less or in some areas almost negligible. This is because the cultivation of tapioca on the vast open land does not offer any habitats or breeding places for **A. dirus**. Tapioca is a small shrub with not enough leaves to provide shade and does not need water from a stream or irrigation system. Without shaded water, the **A. dirus** population gradually became less and, in a short time, the influence of **A. dirus** on malaria transmission in the tapioca plantation area of Cholburi was no longer apparent.

On the other hand, if the introduced crop should be larger trees with plenty of leaves such as rubber plantations, the ground underneath will be suitable for habitats of mosquito vectors, such as **A. maculatus** and **A. dirus**. The presence of both vectors and their roles in the transmission of malaria in old rubber plantations have been observed in Thailand and Malaysia (Notanon 1972, Cheong 1972, Upatham 1985). There is no direct evidence in Thailand to show that **A. dirus** will resume its role in transmission of malaria in the areas where the forest was converted through slash and burn activity into rubber plantations. However, the evidence showing the existence of **A. dirus** population in the rubber plantation in the southern part of Thailand (Upatham 1985) and its high efficiency in transmitting malaria suggests that it could resume its role after the rubber trees grow bigger and thicker. A longitudinal study to show this possible trend is recommended.

Forest fringe slash and burn agriculture in Bo Ploi District, Kanchanaburi Province: the low but persistent malaria risk area

Bo Ploi District of Kanchanaburi is located about 160 km east of Bangkok. Not long ago, this district was recognized as an area of evergreen forest rich in natural resources. Wood, wild animals, mineral ores of tin and wolfram, and gems drew the attention of the migrants from this area as well as from other provinces to work in the jungle. In addition, the province has become an area of sugarcane plantations. This development has created two phenomena. First the penetration of forest for sugarcane cultivation, and second, the migration of people from other provinces, particularly from the dry northeastern region of Thailand, to work as plantation labourers.

In 1961, Kanchanaburi had 91.32% of its land area as forest. Because of the sugarcane industry, the forest area of 4 244 km^2 was rapidly destroyed during the period 1961-1973. In 1982, the province had only 53.73% of its territory as forest (Klamkamsorr and Charuppat 1983).

In the Bo Ploi District the forest was a nature reserve, which means that it is illegal to cut down trees and open new land or to get natural products out. However, due to its richness, the forest was gradually penetrated in several small spots. Trees were cut down and shrubs were burned and replaced by sugarcane. The area in general now consists of newly opened land with sugarcane plantations scattered along the forest fringe, while the forest itself still retains its evergreen structure. In addition to the activities in relation to the opening of new land for sugarcane, the forest was penetrated by some groups of people who went to work in the jungle as charcoal makers, ore diggers, or hunters. Many of them went in after the cultivating season; the time they spent in the forest was variable, depending on the nature of their work.

Because of the expanding sugarcane industry, the migration of labourers from other provinces who came to work on the plantation was very high. In Bo Ploi, malaria was the major health problem, the principle mosquito vectors were **A. minimus** in the low land and **A. dirus** in the forest. The area was in the control phase of the Malaria Control Programme during which active case detection and bi-annual DDT spraying were conducted. The incidence of malaria was brought down to a certain level, but remained the same thereafter. The problem of malaria in this area was the low but persistent transmission. During 1980-1984 the Faculty of Tropical Medicine of Mahidol University, made a study of this problem. Social and economic investigations in Tambon Nong Rhee (canton) revealed two types of migration patterns, long distance migration and short distance migration (Sornmani **et al.**, 1983). The long distance migration consisted of those people from other provinces, who migrated to work as labourers in the sugarcane plantations. The people were new-comers and usually came from non-malarious areas and were not immune to malaria. Malaria infection in this population was higher than in the local population and the mosquito vector responsible for the transmission of malaria among these people was **A. minimus** which bred in the small streams around the villages.

Short-distance migration was mainly carried out by the native residents, particularly those who lived near the forest. They ventured into the national reserve forest for ore digging, charcoal making, or hunting. They exposed themselves to **A. dirus** and got malaria in the forest. Ore digging, which requires water for washing the ore from the soil, has to be done during the rainy season and led to an increased exposure of people to **A. dirus**. Meanwhile, they also created breeding places for this mosquito by excavating for ore. From interviews it was concluded that malaria prevailed in ore diggers rather than in other groups. Another study was made during 1982-1983 by checking blood smears from those who migrated from the villages in this Tambon (canton) into the forest. It was confirmed that prevalence of malaria was higher among those who spent more time in the forest than among those who did not.

Discussion

Malaria risk in slash and burn agriculture in Thailand seems to produce a different picture from that in other countries. The difference could be due to the mosquito vectors and their breeding habitats. In West Africa for example, after cutting down the tropical rain forest for rubber plantations, the population of **A. funestus** declined, while **A. gambiae** increased tremendously and so did the incidence of malaria (Livingstone, 1958). The explanation for this phenomenon is that cutting down of forest trees could offer breeding places for **A. gambiae**, which likes to breed in open, clean running water. With continued cutting of the forest, the soil loses its decayed materials and small tracks of slow running water are formed which constantly fill with tropical rain water. Man's refuse and his villages also provide more breeding places for mosquitos. Lastly, the swamps become open as possible breeding places.

A similar phenomenon was also observed in Southeast Asia. In Malaysia, **A. maculatus** is the principal vector of malaria and it prefers to breed in slow-moving

water exposed to sunlight. It has been observed that the population of **A. maculatus** and the incidence of malaria in Malaysia increased following the clearance of forest and vegetation on hilly land, whether for rubber plantation, tin mining, road or railway construction (Abbas, 1971). When the amount of rubber planting was compared with the malaria cases during 1900-1950, it is interesting to see that the increase of malaria cases was correlated with the increase in jungles areas being opened up for rubber planting.

The two examples from West Africa and Malaysia are in contrast with the situation in Thailand. An increase in malaria risk was noted in the slash and burn areas of the two countries while a decrease was observed in Thailand. Taking the mosquito vectors into consideration, the three countries have different species of mosquito responsible for the transmission of malaria; **A. gambiae** in West Africa, **A. maculatus** in the Malaysian rubber plantations and **A. dirus** in Thailand's forest area. Out of the three, **A. gambiae** and **A. maculatus** need virtually similar types of environments and habitats. Slow running and clean water in the open are their preference, whereas **A. dirus** likes to live and breed in the stagnant water in rock pools, pits, human or animal footprints. All the breeding places of **A. dirus** must be shaded. With slash and burn agriculture, forests are made open and streams and ponds are more exposed to the sun. Subsequently, the new environment encourages an increase in the population of **A. gambiae** and **A. maculatus** (Wisenfeld, 1969, Edison **et al.**, 1957), but does not offer favourable breeding habitats for **A. dirus**.

The replacement of mosquito species after environmental change has also been recorded in Thailand. In the water resource development scheme of Quai Yai Dam Project in Kanchanaburi Province, a reconnaissance survey on health problems was made in 1972-1977 (Sornmani, 1972; 1974; Bunnag **et al.**, 1979). Entomological data showed that in an indigenous village at the forest fringe near the dam site, the populations of **A. dirus** and **A. maculatus** were abundant particularly at the height of the rainy season. Transmission of malaria in this village was perennial. Only a few **A. minimus** were caught in this village. On the contrary, another village in a nearby area where people evacuated from the inundated area and resettled, showed a different mosquito fauna. In this area, forest had recently been opened for cultivation and the entomological samples collected at the same period showed **A. minimus** was the predominant species throughout the year and only one **A. dirus** was found during the time of study. This finding suggests that the resettlement area, where the forest was recently cleared for crops cultivation, destroyed the habitats of **A. dirus** and at the same time created the widespread breeding places of **A. minimus**. In this resettlement village, malaria transmission was active and the role of the main vector changed to **A. minimus**.

7. EPIDEMIOLOGICAL PATTERNS ASSOCIATED WITH AGRICULTURAL ACTIVITIES IN THE TROPICS WITH SPECIAL REFERENCE TO VECTOR-BORNE DISEASES.

David Bradley[1] and Ravi Narayan[2]

Introduction

For most rural populations of the tropics, agriculture is the normative occupation. Therefore our picture of the health and diseases of tropical communities consists of the epidemiological patterns associated with agricultural activities. The patterns are complex and diverse. Tropical peasant agriculture is usually characterized by a high infant and child death rate, malnutrition which may be seasonal, acute respiratory infections and diarrhoea as the main causes of death, particularly of children, frequent tuberculosis and skin infections, trauma and disability, and infection by a variety of endemic parasitic worms and protozoa at high prevalence but showing much regional variation. They will include many vector-borne diseases among which malaria, filariasis, arbovirus infections, schistosomiasis and the other human trematode infections, and the haemoflagellate infections are of particular importance (Table 1). Typically, the subsistence farmer will live with his family on or near to his fields and there will be no sharp boundary between his occupational and general health.

To separate the two is neither feasible nor particularly useful. The person's health problems are experienced as a whole and they are the concern of the Ministy of Health. Some diseases may be linked to specific components of life and of activity and may be open to change, but in general there will be a health care system concerned with all the local diseases and health problems and the agriculture-related diseases can only be approached by observing health changes if the people migrate to a city and nothing else changes in the environment. Even then, the multiplicity of changes is so great that to relate all the differences to loss of agricultural activity will be clearly mistaken.

While it is difficult in the subsistence situation to separate agricultural occupational health problems from the remainder of the community's health, once changes in agricultural activity take place the consequent health changes may be more readily identified and measured. We now therefore concentrate on the health consequences of changing agricultural activity. Health problems may get worse or better - too often different factions of those who study the problem only focus on one of these aspects. We first analyse the types of agricultural change and their health effects, then illustrate the effects of common groupings of changes, and thirdly review a set of particularly important types of agricultural change and their epidemiological implications.

Agricultural change tends primarily to involve alterations in the basic environment, domestic plants and animals, and farming methods (Table 2). The two main types of environmental modification are the provision of increased, or more controlled, water for vegetation growth and the opening up of additional land.

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Water resources developments

Water resources developments have been much studied and may comprise impoundments of water in artificial lakes, sometimes of huge size, and irrigation systems to bring the water to the fields and crops. The resulting increase in availability and diversity of surface water both in area and in duration through the year tends to lead to increased populations of still-water vectors, particularly mosquitoes and water snails. The torrent-breeding **Simulium** vectors of onchocerciasis may have their habitats destroyed by inundation. The converse aspect of water management, drainage of swamps and waterlogged areas, will reduce breeding of mosquitoes and the amphibious snail hosts of **Schistosoma japonicum**. While increased surface waters with more vector habitats and increased vector populations will tend usually to more mosquitoes biting man, contact between snail parasites and man will be dependent on the detailed changes in water availability - man/vector contact may even be reduced due to a dilution effect.

Land Use Extension

Extension of land use brings different vector hazards, chiefly resulting from man's intrusion into new ecosystems with disturbance of parasite life cycles maintained as zoonoses in the undisturbed environment. Leishmaniasis provides a clear example, both in the deforestation on the Amazon region where agricultural settlers are exposed to **Leishmania braziliensis** causing muco-cutaneous disease and in the southern USSR where cutaneous leishmaniasis, transmitted by sandflies between huge populations of the colonial burrowing gerbil **Rhombomys opimus** is a major hazard to farming settlement (Lainson **et al.**, 1963). More lethal problems from sleeping sickness have resulted from agricultural resettlement or patchily cleared secondary forest in South Busoga, Uganda. Audy has emphasized the importance of eco-tones in the epidemiology of vector-borne zoonoses and land use extension creates extended ecotones, edge-effects between different ecosystems (Audy, 1968). Malaria outbreaks in Thailand due to **Anopheles dirus** (formerly called **A. balabacensis**), and described by Sornmani in the previous working paper, are of this type also.

An ecologically comparable situation is where man enters a habitat for some form of agricultural activity of a more hunter-gathering type and thereby enters a zoonotic life cycle habitat. The chewing-gum collectors of Honduras are exposed to **Leishmania mexicana** in this way, which mutilates their external ears (Garnham, 1971). Another example is Kyasanur Forest Disease, an arboviral infection in Karnataka State, South India where affected men and cattle have previously come in contact with **Haemaphysalis spinigera**, a monkey-biting hard tick, during excursions into the forest (Singh, 1971).

Domestic animals and cultivated plants

Changes in plants and animals for domestic use may affect vector-borne diseases, usually because they require changed cultural practices. Many of the high-yielding varieties of rice and wheat, which are the key feature of the "green revolution" have requirements for water and fertilizer that prolong the period of available surface water for vector breeding.

The time scale of health impacts of agricultural change is both variable and complex. A common effect of water resources developments is to decrease seasonal effects, to make irrigation water available in the dry season. So vector presence changes from seasonal to perennial. Often the loss of seasonality will be accompanied

by increased vector populations, but this is not always so. The seasonal malaria of the savannah may be at least as harmful as the perennial transmission of the forest zone in West Africa. The degree of persisting seasonality will depend on small scale decisions. For example, with the multiple cropping of irrigated rice the fields may be planted synchronously, or they may be totally staggered with the consequence that there will always be rice present at the particular growing stage that provides the best habitat for a particular vector. The loss of seasonality may also remove the "hungry period" and its accompanying seasonal overwork and synchronous malaria transmission - that lethal combination which so raises the seasonal death rate in the savannah of West Africa and elsewhere.

Some changes will be of a secular type on a very long timetable. Thus the eutrophication sequence of lake Volta in Ghana is now settling after some 15 years, during which there were massive increases, now to be followed by falls in the submerged macrophytes which acted as habitats for the snail intermediate hosts of urinary schistosomiasis (**Bulinus truncatus rolfsi**) (Obeng, 1975).

The trend towards multiple cropping which depends on both irrigation and appropriate crop varieties can, in the case of rice, increase threefold the period when the ricefields provide breeding habitats, in the absence of measures to restrict mosquito larval survival. However, selection of crop rotations within the year can reduce the time when free surface water is present.

Changes in livestock may affect vector-borne disease patterns in a complex manner. Increased animal populations may direct mosquito biting activity away from man, especially if the livestock pens are located between the breeding sites and human settlements. On the other hand, the stock may act as amplifier populations, allowing the great proliferation of arboviruses normally transmitted at a lower level among wild birds or mammals. Subsequently the infection may spill over into the human population, as may occur with Japanese encephalitis virus, amplified in domestic pig populations. Livestock populations, by increasing food supplies for mosquitoes and tsetse, may also encourage larger vector population than otherwise would be the case, but few quantitative data are available. In the case of schistosomiasis in East Asia, domestic animals are susceptible and may also play a role in maintaining the parasite life cycle in the Philippines and elsewhere.

Farming methods

Changes in agricultural methodology, such as increased mechanization and the use of pesticides, herbicides and fertilizers, will often affect vector-borne disease transmission but it is difficult to generalize about the precise consequences. For example, insecticides applied for agricultural purposes may initially also reduce vector insect populations substantially, they may select insecticide-resistant strains, and they may continue to reduce natural populations of other invertebrates that limit the vector breeding success. The outcome after a time may be more rather than less disease transmission, but the time scale of such changes may vary greatly. Herbicides may render the irrigation channel less suitable for vector breeding (or more so for other species), they may be lethal to snail hosts of trematodes, and the medium-term ecosystem changes may influence the vector populations in complex ways. Eutrophication from fertilizers may indirectly increase snail breeding and have complex effects on the balance of aquatic organisms.

Increased mechanization, discussed by Service in his working paper, has both direct effects through changes in the ricefield or other agricultural environment that may decrease snail populations by better clearing of vegetation from canals, for example, and indirectly may lead to larger fields, better levelling, drainage of marshy areas, and a sharper separation of land and water which will generally tend to decrease vectors of disease.

Most forms of mechanical equipment will also tend to reduce personal contact of farm workers and the aquatic environment. Thus, schistosomiasis transmission will be reduced, so will leptospirosis with its rodent reservoirs, but no invertebrate vector. Where mechanical means are used to harvest crops or cut sugarcane there will be a decreased risk of snake-bite (a substantial hazard in some parts of Asia). Increased sophistication of methods short of mechanisation may also reduce schistosomiasis in those working in water while better clothing will decrease leech bites and insect bites among plantation workers such as tea-pickers.

As agricultural activity and culture methods become more sophisticated and higher yields are systematically sought, a more evenly cultivated landscape will result. The ecotones, patches of waste land and water will be reduced and many disease vectors will decrease. There may however be larger populations of a few vectors whose ecological preferences happen to coincide with the spreading pattern of agriculture.

Changes in people, agents of disease and vectors

Types of agricultural change are outlined above. Either in order to achieve them or following their introduction, substantial human population changes frequently occur. The most obvious are immigration of farmers to newly opened up or newly irrigated lands. Often they may come from over-populated hill areas where endemic malaria and other primarily warm climate diseases are uncommon. Such immigrants suffer heavily: "malaria of the tropical migration of labour" is, for example, a well-known and named entity. The malnutrition which often occurs in the first years in a new site takes its toll and may exacerbate other diseases. The immigrants may precede the provision of health services. Unplanned immigrants, especially fishermen invading water resource developments, may suffer from vector-borne diseases such as schistosomiasis but benefit in economic terms (Pesigan, 1958). Even more unfortunate are indigenous inhabitants displaced by the agricultural innovations of the water resource developments undertaken to provide them. Their health problems are compounded by poverty and upheaval. Resettlement is usually inadequate and a health service to take particular care of new disease hazards is unavailable.

Where the agricultural shift is from subsistence to cash crops , family nutrition usually suffers, at least in the short run, from the loss of local cereals and pulses, sometimes from increased labour demand and less time for child-rearing. The effect of malnutrition on vector-borne diseases is complex and agent-specific, they are not always made worse.

Patterns of settlement often change from scattered homesteads to compact villages. Health care can be made more accessible but some forms of disease transmission - hookworm and other geohelminths, the childhood virus fevers, and other infectious conditions - may become more frequent. Common source disease outbreaks will be larger.

Many activities, and their health consequences, will tend to become less seasonal than before, and the "hungry season" that coincided often with maximal transmission of vector-borne disease, may become less pronounced.

New pathogenic organisms may infect man, new in the sense that they were previously unknown in the locality. This may be because of the environmental changes in agricultural practice described above, introduction by immigrant farm workers, or amplification of zoonotic viruses by introduced livestock. Infections already present may become more prevalent, and in the case of helminthic infections the parasite burden may be increased, with a resulting risk in overt disease. Thus the Egyptian transition from annual flood irrigation to perennial irrigation in the Nile valley has led to a

changed balance between schistosome species and a greater intensity of infection. Vector populations may increase in numbers, or in a few cases decrease, have an extended season of activity and undergo many complex changes.

The emphasis in the above summary has been on the health effects of agriculture as mediated by change in the natural and biological environment. But agricultural change has social and economic effects and their effect on human health may be yet more important. Effective agricultural development will raise aggregate income, with potential health benefits, but it often also increases disparities of income and the poor, usually landless labourers, may become yet poorer and marginal farmers become worse off, with consequences for nutritional status and access to health services. Urbanization of the poorest farmers, with its different health hazards, may be a consequence of agricultural change.

A further group of indirect health effects follows from the various types of seasonal migration related to agriculture, from the regular traditional transhumance of mountain pastoralists to the much larger scale seasonal labour requirements for planting and harvest of sugarcane in Thailand, cotton in the Sudan, and various crops in Asian Turkey. In the last case, problems of welfare taxation greatly complicated control of malaria; both there and in Thailand, as is often the case, migrant labour chiefly suffers from the endemic malaria even though local perception may be reversed, with the migrants being blamed for the malaria which they have in fact contracted only on arrival. Housing for such temporary migrants is not only often very bad, but the transient structures may lack proper walls and be difficult to spray with residual insecticides against mosquito vectors. Permanent agricultural housing over large tracts of South America is liable to colonization by reduviid bugs, which by their nocturnal blood feeding on inhabitants may transmit Chagas' disease.

Where livestock shares the farmer's dwelling at night, other vector-borne disease problems are locally significant. Cattle ticks of the genus **Ornithodorus** in Tanzania will travel up the bedposts, especially if they are fixed into the ground, and transmit relapsing fever among the inhabitants. In areas of sheepherding, domestic dogs become important in the transmission of hydatid disease to man while rabies is a hazard also.

The patterns of disease observed in different agricultural communities will depend upon the specific agricultural variables listed in Table 1 together with the local features of climate, degree of socio-economic development, and cultural variables. Certain broad patterns may emerge, in different geographical regions, though the vector-borne diseases in particular will tend to show micro-geographical variations in both the types and prevalences of diseases encountered.

Implications of types of agriculture

Asian rice cultivation will be dominated by malaria, schistosomiasis and Japanese encephalitis, with smaller contributions from gastro-intestinal and hepatic flukes. But all these diseases are patchily distributed and in many areas malaria is prevalent but unrelated to agricultural activity. Similar problems occur with irrigated rice elsewhere, though different arboviruses will replace the Japanese encephalitis, especially in the Americas, and the filariases will play a variable role.

The problems of extending cultivable land into forested areas are likely to include zoonoses such as leishmaniasis, sleeping sickness and some arbovirus infections, while some Asian malaria vectors flourish in such ecotones as does scrub typhus.

Plantation agriculture has usually followed control of malaria, and particular health hazards are related to labour-intensive activity in close contact with trees and shrubs where insect stings, leeches and snakebite may be frequent. A range of vector-

borne diseases may occur but are more easily controlled than in the unorganized rural agricultural sector of contiguous areas.

The move to highly mechanized advanced agriculture is accompanied by massive falls in the farming population, larger plots and more capital-intensive methods that usually tend to reduce the hazards of vector-borne disease. Contact with vector snails will tend to fall, even if they are present in the water bodies, and the main residual problems will be vector mosquito breeding if rice or similar crops are grown and health hazards from seasonal labour migrants where these are needed for harvesting. Mechanization and/or sophistication of technology are invariably involved with greater capital-intensive production reducing labour demand and hence increasing rural unemployment, especially if alternative employment through rural or urban industrialization cannot keep pace. This could further complicate the situation of poverty and disease.

Particular issues of agricultural change

Various Arcadian memories or dreams exist concerning healthy agricultural practices and environments in the past, and hunter-gatherers seem often to have lighter levels of parasitic infections that do those in settled agriculture. The ancient hydraulic agricultural communities of Sri Lanka were said to have a relatively low incidence of vector-borne disease as a result of having a network of small units serving limited populations, without use of pesticides and fertilizers but with careful maintenance of tanks and canals and carefully followed cycles of seasonal flooding and drying out of the channels. Similarly, in more recent times the Sudan Gezira Board achieved good control of schistosomiasis and of malaria by a complex of environmental and behavioural measures enforced with an iron hand in the earlier years of that irrigation scheme. It is far from clear how far, in the absence of coercion or very strong incentives, it is possible to have an environmentally and behaviourally determined relatively safe agricultural programme in the tropics, involving water resource development, but certainly this area needs further study.

The practical issues of attempting a return to this Arcadia are raised by considerations that have increased since the availability of greater evaluated experience of "the green revolution" and the awareness of an increasing range of detrimental effects that have accompanied the increased food availability - not the least of which are the pesticide "treadmill" effect, pesticide hazards, and the socio-economic effects mentioned earlier. The quest for sustainable agriculture - that produces higher yields but with very limited fertilizer and other modern sector inputs - has been gaining ground through experiments in Japan, India, USA and UK. This situation may be good for environmental control of vectors but little directly relevant research is yet available and needs to be planned for.

Development strategies involving both agricultural and industrial interventions are increasingly beginning to focus on those sections of society who do not much participate or benefit from the existing modes of development. While environmental and socio-economic changes in the community have been adequately documented, only in some limited specific cases have data about the health and nutrition effects of agricultural development been applied in impact evaluation. Much more needs to be done.

The analysis of health consequences of agricultural change has predominantly considered one disease at a time and traced the biological and behavioural determinants of transmission. Less often, a single change in agriculture or a single intervention has been considered in relation to all its health consequences, as when the effects of increasing irrigated rice fields or introducing piped water are considered. But the

farming family see their health as a whole in relation to themselves rather than a single agricultural change or occupational hazard. Moreover the farming community is essentially a stratified community divided into different groups by socio-economic status, land ownership and wage relations. Agricultural change whether single or multidimensional, affects different groups in different ways - quantitatively and qualitatively. There is a need for community based epidemiological studies that will consider agriculture as one of the many determining variables for health and measure its impact on the stratified agricultural community. This is not only to give a sense of proportion but also to see the problems and thus seek solutions from the viewpoint of the farmer and the agricultural community.

Table 1. Major vector-borne diseases that may be related to agriculture

<u>Protozoa</u>	
Malaria	Anopheline mosquito vector may breed in standing water
Sleeping sickness	Tsetse-borne disease related to extending land use into forest
Chagas' Disease	Transmitted by bugs living in walls of houses, especially when livestock there
Visceral leishmaniasis	Sporadic, sometimes epidemic in semi-arid regions, sandfly transmitted
Cutaneous leishmaniasis	Rodent reservoirs disturbed in Asian land use
Muco-cutaneous leishmaniasis	Forest zoonosis of Amazon forests, to man during deforestation
<u>Trematodes and Cestodes</u>	
Schistosomiases	Major irrigation problems spread by aquatic and amphibious snails
Hydatid	Dog tapeworms, larva usually in sheep, harmful to man in sheep-herding areas
Other tapeworms	Problems where undercooked beef and pork concerned
Other trematodes	Transmitted by snails through undercooked freshwater animals
<u>Nematodes</u>	
Guinea-worm	Transmitted through defective water supplies by water-flea type crustacean. Big effect on agricultural productivity
Filariases	Transmitted by anopheline and culicine mosquitoes
Oncherciasis	Transmitted by fast-water breeding **Simulium** flies

Table 1. (continued) Major vector-borne diseases that may be related to agriculture

Other microbes	
Relapsing fever	Tickborne problem where stock and man share accommodation
Yellow fever	Hazard at forest edge (and in urban areas)
Dengue Japanese encephalitis Other encephalitides Other arbovirus infections	Viruses transmitted by mosquitoes, mainly culicines, breeding in irrigated fields and standing water
Scrub typhus	Mite-borne zoonosis of the forest edge
Non-vector-borne diseases	
Leptospirosis	Especially problem of marshy and irrigated agriculture
Rabies	Hazard of pastoral areas where dogs used
Snakebite, leeches	Hazard in forest plantation agriculture

Table 2. Epidemiologically relevant aspects of agricultural change

PRIMARY AGRICULTURAL CHANGES	New or Qualitatively Changed	Increased Quantitatively
ENVIRONMENT		
Water resources development	Reservoirs, dams. Land drainage. Irrigation schemes	Irrigation canals
Land use extension	Clearing, deforestation Extensive ecotones	
ORGANISMS		
Plants	New High-yielding varieties Move to cash crops Intercropping	Multiple cropping
Livestock	New breeds	Increased animal husbandry
CULTURAL METHODS		
Chemicals	Pesticides Herbicides	Fertilizers
Machinery	Mechanization	

Table 2. (continued) Epidemiologically relevant aspects of agricultural change

SECONDARY EPIDEMIOLOGICAL CHANGES

People	Settlement Changes in Seasonal Patterns Nutritional status	Immigration
Vectors	Species changes	Population changes
Disease agents	Species changes New introductions New hosts acquired	Amplification by stock

8. PREDOMINANT AGRICULTURAL PRACTICES AND THEIR BEARING ON VECTOR-BORNE DISEASE TRANSMISSION IN THE WHO EASTERN MEDITERRANEAN REGION

H. Rathor[1]

Introduction

All the countries of the Eastern Mediterranean Region are developing countries, and agricultural development is one of the most important factors contributing to their overall economic development. Although agricultural development has brought some prosperity to the people, it has, in many cases, also increased their disease vector problem, because of the ecological changes caused by the essential introduction of perennial water into an otherwise arid or semi-arid environment.

The major water-associated vector-borne diseases in this Region are malaria, schistosomiasis, and filariasis (including onchocerciasis). Table 1 lists the diseases according to their significance in different countries.

Agricultural practices

* Irrigation and malaria

There are many examples of intensification of disease problem due to man-made irrigation systems. The Gezira area in Sudan dating from the 1920s presents a classical example of how agricultural development can affect vector-borne diseases. Before the construction of the Sennar Dam, malaria was mostly a seasonal disease in this area. But the irrigation canals provided suitable breeding places for the malaria vector **Anopheles arabiensis.** This resulted in a malaria epidemic in 1950 when hundreds of people died and one-third of the crops remained unharvested. Efforts were made to control malaria but again in 1971-1974 a serious epidemic occurred. In 1979 the Blue Nile Health Project was started to control water-associated diseases, including malaria, through environmental management and community participation.

In Pakistan, the Indus Basin covers 70% of the gross area of the country. The basin is traversed by five large perennial rivers and numerous seasonal rivers. Nearly 14 million hectares of land in the basin are irrigated by five large and medium size dams, 20 small dams, 18 river diversion works, 62 000 kms of canals, 600 km of surface drains. Ample evidence exists that the areas that once had low incidence of malaria, became hyperendemic regions after the implementation of water resource development projects.

In Pakistan, the Chashma Right Bank Canal (CRBC) shows how, if care is not taken, man-made irrigation system can result in the formation of uncontrolled water bodies which become breeding sites for mosquitos and other vectors of disease. CRBC is an irrigation canal taking off from the right bank of the Indus River at the existing Chashma Barrage, and will run almost 270 kms. Its distributories and minors will run

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an aggregate of another 650 km. to take the water to the fields and the project will irrigate 140 000 ha of NWFP and 88 000 ha of Punjab Province when finally commissioned in 1991-1992.

During stage 1, i.e., when the first 38 km of the canal were tested it was observed that it lost water through the bed and shoulders. At certain parts seepage was as high as 45% of the flow in the canal; this water was not only lost but submerged the standing crops and villages and produced breeding places for malaria vector mosquitos and other vectors of disease. Remedial measures such as lining of the canal and construction of drains to take care of seepage are expected to rectify the situation. The secondary and tertiary distribution channels also play a major role in propagation of malaria vectors. For example, **A. culicifacies**, the most important vector of malaria in Pakistan, thrives in slow flowing fresh water tertiary channels. The water, which either seeps out or leaks out of these channels forms very shallow fresh water pools which become ideal breeding places for **A. culicifacies.** These breeding places also play a significant role in malaria transmission in the adjacent villages of Punjab province, which is the most malarious part of the country. A number of other countries are concentrating on the construction of dams and irrigation schemes. For example, in the Democratic Republic of Yemen, construction of dams in the second and third governorates has given an economic boost to the population through agricultural development; but within the limits of Lahej and Abian, the areas of maximum agricultural yield, malaria is endemic with perennisal transmission.

In Yemen, the Marib Dam was recently constructed to retain the excess run off of the flash floods from the catchment area of Wadi Dhanah and the associated irrigation scheme. A recent study conducted to assess the possible impact of the dam and the associated irrigation system on the vector-borne diseases concluded that both malaria and schistosomiasis are two likely candidate parasitic diseases to establish themselves endemically, with probably recurrent epidemic waves, unless timely and adequate preventive measures are applied.

It must be noted that it is not the agricultural development and associated irrigation schemes but the wrong or unplanned agricultural development which create vector-borne disease problems. A good example of properly planned agricultural development is that of an irrigation project in the Al Hassa Oasis, Saudi Arabia. This project was implemented in the late 1960s to increase the area under cultivation and reduce wastage of water, improve irrigation practices and provide adequate drinking water. Prior to project implementation malaria had been a problem, but since 1973 no indigenous cases of malaria have been reported. This success was basically attributable to the lining of irrigation canals, efficient drainage and recovery of marshy lands by planned forestation.

* Irrigation and schistosomiasis

The snail intermediate hosts of schistosomiasis are adapted to a wide range of environmental conditions in the Eastern Mediterranean Region and breed in different habitats such as streams, irrigation canals, ponds, borrow pits, flooded areas, lakes, water cress fields and rice fields.

The schistosomias problem in Sudan is closely associated with the irrigation system and water courses of the Nile. Before the establishment of the Blue Nile irrigation scheme, schistosomiasis was non-existent or was reported only sporadically. Now the main canal, starting from the Sennar reservoir, branches into 20 large canals which subdivide into minor canals. The irrigation canal system tends to be filled with silt and becomes choked with vegetation, creating an ideal habitat for the snail host of **Schistosoma mansoni** and **Schistosoma haematobium.** The main agricultural lands lie in Gezira, Managil and Rahad schemes, where both forms of schistosomiasis occur in close association with the irrigation systems and water courses. In Egypt schistosomiasis is considered to be the most important public health problem. **Schistosoma haematobium**

prevails along the entire length of the Nile Valley including the delta, but **Schistosoma mansoni** which was formerly considered to be limited to lower Egypt and to the Nile Delta, has invaded Upper Egypt and Lake Nasser after the construction of Aswan Dam.

Jordan was one of the few countries in the Region which was considered to be free of schistosomiasis, but recently the new dams and canals have been found to have propagated the snail intermediate host of schistosomiasis, **Bulinus truncatus.** More than 40 breeding sites of **B. truncatus** have been found. One of the sites is the newly built King Talal Dam. Zarqa river, which was free of snails in 1980, had snails in large areas above the dam in 1982. Kafrain Dam, previously free of snails, was found infested in 1984. Between 1984-86, 31 indigenous cases of schistosomiasis were detected in southern governorate of Karak.

* The role of crop selection and cropping pattern

One of the important changes in agricultural practices is the change from partial to perennial cropping resulting from improved methods of irrigation. For example, in ancient Egypt and still in some parts of Upper Egypt only one crop was raised each year, utilizing Nile flood water captured in fields by constructing dikes. Perennial irrigation, which started during the last century provided water supply all the year round enabling cultivation of several crops. This change to perennial irrigation in Upper Egypt, resulted in a 30 fold increase in the percentage of population infected with schistosomiasis.

The other example is again the Gezira area in Sudan. After the construction of the Sennar Dam, at first only cotton was grown therefore the peripheral irrigation ditches could be regularly dried out, not permitting the malaria mosquito developmental stages to complete their cycle and emerge as adults. As a result malaria was kept under control. Later, with the introduction of multiple cropping practices, whereby wheat, millet, rice, groundnuts were grown, the practice of drying out the peripheral ditches was abandoned. The permanent slow flowing water in these ditches provided breeding sources for **A. arabiensis** and resulted in the malaria epidemic of 1950.

The practice of cultivating crops which necessitate stagnant water in the field, for example rice cultivation, contributes considerably to the disease problems. In the Eastern Mediterranean Region more than 70 species of anopheline mosquitos exist but less than 18 species are incriminated as malaria vectors. Vectorial capacity depends on the longevity of mosquitos, in addition to a number of other factors. In order to be able to transmit the disease, a female Anopheles must live beyond the period of intrinsic cycle of the parasite (8-10 days) to reach the infective stage. High humidity of the air increases the longevity of mosquitos, and rice cultivation tends to increase humidity. **Anopheles pharoensis** is widely distributed in Somalia, Sudan and Egypt. It is a known vector of malaria in Egypt, where its longevity is markedly extended with the increase of relative humidity from July to September. The decline of efficiency of this mosquito has been observed after September as the rice fields dry up. Persistence of malaria in Kalyubia governorate is suspected to be mainly due to extensive rice cultivation.

* Agricultural labour

Agricultural development resulting in better socio-economic conditions attracts labourers from within the country as well as from neighbouring countries. This aggregation of labour force in agricultural areas acts as a source of parasites. For example, in the Gezira, permanent and temporary labourers for cotton picking and other agricultural tasks, and for maintaining the irrigation system, come from Western Sudan and from bordering countries such as Chad or Nigeria (El Gaddal, 1985). These immigrants live in small settlements without clean water or proper sanitary conditions and are totally dependent on canal water for all purposes. Such a combination of human migrant populations and irrigation leads to an increase in malaria and schistosomiasis.

Another example is that of United Arab Emirates where malaria is under control and the emphasis is on speedy development of agriculture by introducing irrigation. The agricultural labour force mostly consists of expatriates coming from malarious countries. They regularly return home and may come back as fresh sources of infection. A number of other countries, for example Jordan and Saudia Arabia, face the potential danger of immigrant labourers who may provide a reservoir or source of reintroduction of parasites and disease.

Table 1. Relative significance of important water-associated vector-borne diseases in EMR countries.

EMR countries	MAL	SCH	FIL	ONC	DRA
Afghanistan	A[1,2]				
Bahrain	B[2]	C			
Cyprus	C[6]				
Dem. Yemen	A[1,4,5]	B		C	
Djibouti	B[4]				
Egypt	B[5,7]	A	B		
Iran	A[1,2,3]	C			C
Iraq	A[2,3,6,9]	B			
Jordan	C[3,5,6]	C			
Kuwait	C[2]				
Lebanon	C[5,6]	C			
Libya	B[5]	C			
Morocco	B[10]	C			
Oman	A[1,2]	C	C		
Pakistan	A[1,2,5]				B
Qatar	C[2]				
Saudi Arabia	A[2,3,4,5]	B			
Somalia	A[4]	A	C		B
Sudan	A[4]	A	C	A	B
Syria	A[3,6]	B			
Tunisia	C[10]	B			
U.A.E.	B[1,2]				
Yemen	A[1,4,5]	A		C	C

A = Disease of great public health importance
B = Disease of comparatively low significance
C = Disease of minor extremely low significance

MAL = Malaria
SCH = Schistosomiasis
FIL = Filariasis
ONC = Onchocerciasis
DRA = Dracunculiasis

Malaria transmission by:
(1) **A. culicifacies** (2) **A. stephensi**
(3) **A. superpictus** (4) **A. arabiensis**
(5) **A. sacharovi** (6) **A. sergenti**
(7) **A. pharoensis** (8) **A. fluviatilis**
(9) **A. pulcherrimus** (10) **A. labranchiae**

9. AGRICULTURAL PRACTICES AND THEIR BEARING ON VECTOR-BORNE DISEASES IN THE WHO WESTERN PACIFIC REGION

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Introduction

The writer has reviewed documents and reports concerning his visits to various countries of the Region during the past 10 years. Information related to agricultural practices has been extracted and presented herein. Admittedly, this information is preliminary in nature and does not provide an in-depth analysis of the situation. This brief overview, however, can be looked upon as a starting point in identifying specific agricultural practices that could be subjects of future studies.

Observations in various countries

The great reliance on the use of DDT as an indoor residual spray during the past 30 years has hampered the implementation of environmental management measures requiring skilled engineers. For example, subsoil drains were installed before the advent of DDT to control **Anopheles maculatus** in ravines in Kuala Lumpur, Malaysia, and also to control anopheline breeding in rubber plantations in Democratic Kampuchea and Viet Nam. These permanent measures eliminated anopheline breeding in relatively small areas in relation to the total malarious area. However, some extensive drainage systems built 40 years ago in Malaysia as well as in the Philippines are still operating effectively today.

Although there are exceptions in some areas of China and Japan, controlling the breeding in ricefields of **Culex tritaeniorhynchus** and related vectors of Japanese encephalitis (JE) by environmental management techniques has not been promising. Ricefields are managed and manipulated primarily by agricultural personnel for agricultural purposes, and the concept of intermittent irrigation is an attractive term, but is not being widely applied.

There is a recognized need in this region for the application of practical, inexpensive and acceptable methods of environmental management to control the pond and swamp breeding of **Mansonia** vectors of brugian filariasis. People go into the swampy forest to collect fruit such as durians or for other purposes, and run the risk of receiving infective mosquito bites from filariasis and also malaria vectors. This aspect of human behaviour deserves more attention in order to consider ways to modify it and to identify high-risk groups which should present themselves or be traced for blood examination and treatment, if necessary.

* China

A. sinensis is the most important of the four major vectors throughout South East China in low-lying swampy areas, particularly associated with ricefields. It is the

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major vector throughout the vast plains areas of China and is considered to be the sole vector in the lowlands between the Huang (Yellow) River and the Huai River. About one million cases of vivax malaria have occurred in recent years.

A. dirus (= **balabacensis**) occurs in the southern part of Yunnan and Hainan provinces. It is also found in Taiwan province, the southwestern border of Guangxi and the southeastern corner of Tibet. The vector is active throughout the year. In Hainan Island, the peak of malaria attacks occurs in June and outbreaks of malaria rarely occur among the local immune inhabitants. Severe epidemics however have occurred among large numbers of immigrants engaged in agricultural work within a few months of arrival.

In Zhouixan County, Shandong Province, converting rice-growing areas to wheat production has apparently contributed to the elimination of JE cases in recent years. In addition, larval breeding sites in the communes have been sprayed with fuel oil, and animal shelters were sprayed with a residual insecticide produced in China. The clearing of vegetation and weeds around houses and within the communes has eliminated favourable outdoor vector resting sites in close proximity to the human population.

In the Shanghai area, 50 JE cases were reported per 100 000 population in 1965 as opposed to only 2.3 cases in 1978. This marked reduction in cases cannot be attributed to any single control measure. Special clean-up campaigns are organized several times a year to improve the condition of the environment and to make it less favourable for JE vectors to find suitable breeding and resting sites close to houses. Some of these activities have included improved irrigation and drainage systems; however, significant numbers of mosquitos still occur in ricefields. Some control measures of the 50 anti-epidemic stations in Shanghai have focused on spraying larval breeding sites in early spring followed by space spraying adult summer populations at peak times. In this region, pigs have been shown to be the main host reservoir. Spraying pig shelters with a residual insecticide is a major control method. In addition, light traps have been used to capture adults in order to reduce the population density. Vaccines have been used on a small scale to vaccinate pigs and children. Where intermittent irrigation is practical, a reduction in the density of JE vectors breeding in ricefields would be expected.

Some agricultural-related vector control practices in China are as follows:

(1) Clearing of vegetation up to 500 metres from the village perimeter, combined with land reclamation (planting orange trees, for example, to prevent scrub vegetation from growing back) to obtain **A. dirus** free localities in Hainan Island.

(2) Intermittent irrigation practices in ricefields, to conserve water and increase yield, which are carried out in large areas of Henan Province in East China under agricultural auspices, resulting in reduced densities of **A. sinensis** and **Culex** vectors of Japanese encephalitis.

(3) Community collaboration with fisheries personnel in the rearing and release of fish (**Tilapia, Ctenopharyngodon**, common carp, etc.) in channels in and around rice fields, in which case weeds have been consumed, rice yields have increased due in part to the fish excreta, and the grown fish have been used for human food.

(4) Among communities living in the towns of Beiha and Doong Xing in Guangxi Province in southern China near the Viet Nam border, placing of fish (**Nilotica** introduced from Egypt, **Tilapia** and **Claris fuseus**) into water containers to control **Aedes aegypti** in order to reduce the risks of dengue fever outbreaks.

(5) The spraying of cattle with permethrin, and the impregnation of mosquito nets with the same pyrethroid or deltamethrin for distribution to the community have also been considered in high density **A. sinensis** rice plain areas of East China, where the malaria incidence had been above 5% and DDT indoor spraying had been withdrawn.

(6) Providing a "dry belt" around human habitation in the planning of future rice cultivation projects. Limiting a belt of at least 500 metres around villages to dry farming would provide some protection to the population against mosquito invasion and hence infection of malaria and JE.

* Japan

Following the influx of imported cases of malaria after the Second World War, the number of reported malaria cases decreased to only 28 in 1958. The complete control of malaria in Japan today (vigilance is maintained and imported cases still occur each year) has been achieved without a specific control programme, except in a few localities.

Although no specific national antimalaria programme in Japan was established, there have been control projects directed against Japanese encephalitis since 1966, involving vaccination and vector control. The main malaria and Japanese encephalitis vectors, **A. sinensis** and **C. tritaeniorhynchus**, respectively, both breed in rice fields. There are a number of probable explanations for the marked decline in cases of both diseases, which will not be listed here, except for those touching upon agriculture-related community activities as follows:

(1) Marked reduction of vector populations through the extensive use of insecticides for agricultural purposes.

(2) Drainage and irrigation practices to increase yields, which are harmful to mosquito larvae, especially the extended period of drying in August.

(3) Moving cattle and pigs away from houses to reduce man-vector contact.

(4) Improvement of housing, basic sanitation and living standards, especially in rural areas.

* Republic of Korea

Improvements in standards of living, better housing and basic sanitation facilities, and establishment of model villages for gradual expansion to rural communities have contributed to the control and diminishing importance of vector-borne diseases. As in Japan, farmer pesticide applications have lowered the density of the Japanese encephalitis vector, **C. tritaeniorhynchus**, in the rural rice growing areas. Although the main malaria vector, **A. sinensis**, also breeds in ricefields, the pesticide applications have not had as noticeable an impact in reducing vector density. An effective national malaria eradication programme has been most in controlling malaria.

Some specific agriculture-related measures being promoted by health officials include the following:

(1) Collaboration with agricultural officials and farmers in selecting and using herbicides at the time of transplanting rice, in May and June, which are not toxic to larvivorous fish.

(2) Exploring whether farmers can be encouraged to dig small "water holes" in and near ricefields to promote the greater survival of larvivorous fish during the winter months.

(3) Collaboration with the agricultural extension and training programme in providing information to farmers on the safe use of pesticides and especially the precautions to be taken when applying them.

(4) Using a surveillance system based on antibody conversion in sentinel pigs and mosquito light trap captures to warn communities of potential Japanese encephalitis outbreaks. If outbreaks occur, health education activities are stepped up and the media are used to advise communities to give greater attention to personal protection measures and adult mosquito control in and around their houses during the high-risk period.

Vector control measures against **C. tritaeniorhynchus**, the JE vector, were intensified in 1983. One of the major policy changes was a directive from the Ministry of Health to the provincial health officers to carry out the residual spraying of cow and pig shelters. Insecticides were provided free of charge by the government, and farmers were requested to spray their shelters every two weeks from June through September. This programme appears to be progressing well and may have had an impact in greatly reducing the number of JE cases between 1984 and 1986. Entomological data show a marked reduction in vector densities after the spraying programme commenced.

With respect to leptospirosis, an outbreak of a haemorrhagic fever type of disease occurred in the Wonju and Kwangju area in August 1984. About 35 farmers became seriously ill and haemorrhagic fever was suspected. Epidemiological studies revealed that the likely causative agent was **Leptospira interrogans** serogroup icerohaemorrhagiae. Two isolates were obtained from human patients and 5 isolates from the Korean line-backed (or striped) field mouse, **Apodemus agrarius coraea.**

The leptospirosis was associated with over flooding of ricefields during a period of heavy rainfall. Thus, farmers were exposed to infective leptospirosis by entering these waters before the flooding subsided. Areas of their unprotected arms or legs were openly exposed to infection, and provided a route of entry for the leptospirosis parasite. Further studies involving the collection of field rodents are to be carried out by the Medical Entomology Division of the National Institute of Health in Seoul.

* Malaysia

Malaria, scrub typhus and leptospirosis can occur in oil palm plantations and other land development schemes. Relevant issues recently highlighted are as follows:

(1) Persons with fever, chills and headache in oil palm plantations could have malaria and/or scrub typhus. Scrub typhus has been particularly prevalent in oil palm workers and is one of the most common causes of fevers among rural populations in South and central peninsular Malaysia.

(2) State public health engineers and the Federal Land Development Authority should ensure that contractors are made aware of the need for draining cleared land to minimize breeding of **A. maculatus.**

(3) Contractors should take greater responsibility in promoting anti-malaria measures among their workers. This involves the screening of houses and facilitating prompt diagnosis and treatment of fever cases.

(4) The following preventive measures against scrub typhus are suitable health education topics:

(a) Keeping weeds and undergrowth cleared in oil palm, rubber and coconut plantations to reduce harbourage for rodents and mites. This will also reduce the risk of snake bite.

(b) Burning the discarded fronds (lower leaves) of oil palms to also minimize rodent and mite populations.

1100

(c) Placing of black plastic squares (8 cm x 8 cm) in vegetation to facilitate observations of orange-coloured vector mites.

(5) Oil palm plantations are also high risk areas for contracting leptospirosis. Rodent urine can contaminate the ground and barefooted population workers can become infected. The flushing action of heavy rains may also cause drains and rivers to become quickly contaminated. Wading, bathing or swimming in flowing streams should be avoided. Other high-risk locations are ricefields and jungle areas.

10. AGRICULTURAL USE OF PESTICIDES AND THEIR EFFECT ON VECTOR BORNE DISEASE TRANSMISSION IN THE WHO REGION OF THE AMERICAS

D.N. Bown[1]

Introduction

Despite major advances and growth in industrial sectors, Latin America is heavily committed to agro-industrial production and will remain so to provide food for its ever increasing populations. In tropical regions, a large percentage of the work force is employed in various aspects of food production, processing, distribution and in the manufacture, transportation and application of agricultural chemicals such as fertilizers and pesticides.

The dependence of the agro-industry on the application of pesticides to maintain production quantity and quality is not disputed . However, there has been worldwide concern about the effect of the massive insecticide usage on the environment.

The extensive use of insecticides is of concern, not only because of the problems of pesticide poisoning and of food contamination, but also because of the effect that they have on public health programmes that rely on these compounds. There is an intensive agricultural use of a large number of different pesticides, often applied from the air at high rates, frequently highly toxic and many of which are persistent. Due to the method of application most of the insecticide never reaches its target organisms but instead is carried far away by wind and water. This results in the contamination of habitats nearby and the exposure of insects of public health importance. At first this exposure may be beneficial and vector populations will be reduced. However, problems arise when these populations adapt to new selective pressures and become resistant. When this occurs, insecticides that are applied specifically to control vector populations become ineffective.

Vector-borne diseases

In the Americas, leishmaniasis, onchocerciasis, Chagas' disease (American trypanosomiasis), dengue, yellow fever, viral encephalitis, and malaria are the major diseases transmitted by insects. Leishmaniasis, onchocerciasis, and yellow fever occur in limited areas and, as a result of control efforts, are focal. Dengue, trypanosomiasis, and malaria are controlled on a national level in only a few countries by insecticide applications. Since very little information is available on the effect of agricultural spraying on dengue and Chagas control programmes, the occurrence of multiple resistance in the corresponding vectors is only briefly mentioned below:

* Aedes aegypti

Aedes aegypti, which is the major vector of yellow fever and dengue, is found extensively in Latin America. In the 1940s, 1950s, and 1960s intensive efforts were made to eradicate this vector and success was obtained in 17 countries. However, since that time most countries have been reinfested and control efforts have not been re-established. In general this vector has been found to be resistant to organochlorine.

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insecticides but remains susceptible to organophosphates such as malathion and temephos. The vector is domesticated with both larvae and adults being found in and around houses. As a result its exposure to agricultural applications of insecticides is limited.

* Triatomid Bugs

Venezuela, Brazil, Uruguay, Argentina and Chile are the only countries in Latin America that have programmes to control triatomid bugs which are responsible for the transmission of Chagas' disease. In Venezuela resistance to dieldrin, DDT and propoxur has been reported from 1977-80 in populations of **Rhodnius prolixus**. In Ecuador, **R. prolixus** and **Triatoma dimiata** were found to be resistant to DDT and dieldrin, however they are still susceptible to malathion and propoxur. The relation between the development of resistance by triatomids to insecticides has not been studied extensively; however, since the major vectors are found mainly in and around houses it is probable that their exposure is also limited to areas where houses are close to the crops.

* Malaria

By far the greatest concern worldwide with the development of resistance has occurred in malaria control programmes, a total of 50 species are now recorded as resistant to one or more pesticides. The World Health Organization recognized in the 1950s the potential problem of anopheline resistance and supported the attempt to eradicate malaria before resistance fully developed. Twenty years later it had to be accepted that the race had been lost. As a result eradication programmes have now been reduced to extended control programmes.

In the Americas, resistance to organochlorine insecticides appeared shortly after the eradication campaign began. The evidence indicating that heavy agricultural spraying was responsible for its rapid development came from strong correlation shown to exist between the intensity of pesticide use on crops and the degree of extended vector resistance. For example, resistance in Mexico was discovered for the first time in 1958 in the State of Morelos in **A. pseudopunctipennis** and subsequently in **A. albimanus** in Chiapas. At that time dieldrin was being used in the house spraying programme and had to be replaced by DDT. A little later, resistance to DDT was observed in **A. albimanus**. The area of greatest resistance occurred along the coast of Chiapas where cotton was intensively cultivated. In 1959 resistance to DDT was detected in the cotton producing areas of Guatemala.

The first signs of impending resistance to organophosphorous insecticides in field populations of **A. albimanus** was reported in 1965 in Guatemala and Nicaragua, where a decrease in susceptibility to malathion was observed. Aerial applications of malathion against adults in the coastal areas of El Salvador in March of 1969, resulted in considerably less control than that of laboratory populations. The decrease in susceptibility occurred only in areas of intensive cotton cultivation. These areas were subjected, almost weekly, to massive pesticide applications during 6 months of the year. Shortly thereafter evidence was obtained that indicated that resistance appeared not only to malathion, but also to other organophosphates such as parathion, methyl parathion, fenitrothion and carbamates such as propoxur and carbaryl (Georghiou **et al.**, 1974).

It was also ascertained that when the seasonal application of insecticides was initiated a corresponding drop in vector density occurred. The coastal plain of El Salvador is a high malaria transmission area where multiple resistance of **A. albimanus** to insecticide occurs. Hobbs (1973) examined the effect of agricultural spraying on the **A. albimanus** populations. The study site was an area of intensive cotton production where heavy aerial applications of parathion, methyl parathion, malathion, azudrin, DDT, carbaryl, were carried out in the fields from August to December each year. It was observed that when the applications began in August, the larval and adult populations fell to zero, whereas control sites that were 10 km from the aerial applications maintained high vector densities.

The types of resistance that developed also corresponded to the kind of insecticides being applied on the crops. Calderon (1987) reviewed the use of pesticides in El Salvador and listed those most commonly used for the various crops. A wide variety of insecticides is being extensively applied, many of which have caused cross-resistance in mosquitos due to a mode of action similar to insecticides used in public health. Coffee is sprayed with malathion, actellic, permethrin, and deltamethrin and cotton is sprayed with permethrin and cypermethrin. These are some of the alternative insecticides that will be used when mosquitos develop resistance to the ones presently being applied. These insecticides are the latest to be registered for use in malaria control, however, mosquitos are being exposed to them even before the first house is sprayed. DDT has not been used in agriculture in El Salvador for the past seven years due to government prohibition.

When the degree of resistance was studied in detail over a period of time, it was observed that it fluctuated seasonally. In El Salvador, Georghiou **et al.**, (1974) registered a seasonal change in resistance to numerous insecticides. When compared to susceptible laboratory strains it was ascertained that in February, immediately after the cessation of cotton spraying, resistance had increased 100x to propoxur, 443x to carbaryl, 178x to malathion, 158x to parathion, 145x to methyl parathion, and 45x to fenitrothion. By July, resistance decreased somewhat but would return again to higher levels when cotton spraying commenced.

In Southern Chiapas, Mexico, Rios **et al.**, (1987), observed similar changes in the resistance levels of **A. albimanus.** He compared the resistance in 3 agricultural zones in January, when the spraying season ends, with June of the same year, just prior to the next spraying season. In areas where the main crop was cotton it was observed that resistance levels to DDT, propoxur, fenitrothion, and malathion decreased 6.8%, 35.2%, 7.6% and 21.1%, respectively, after discontinuing the application of insecticides. No resistance to fenthion and chlorfoxim was observed. The resistance level to deltamethrin increased 15.8% during the same period.

Similar results were obtained in the banana plantation areas, except that resistance to fenitrothion increased by 8.8% instead of decreasing. This was not expected because in general less insecticide is used in the cultivation of bananas than for the treatment of cotton crops. The reason for this may be that there are cotton fields in Guatemala that are close to the banana plantations on the border. In mixed cultivation areas no change in resistance was observed for DDT or propoxur, however an 8.7% decrease in resistance was encountered to fenitrothion and a 3.6% decrease for malathion. An increase in resistance of 27.2% was observed with deltamethrin. Insecticides such as DDT, fenitrothion and deltamethrin all had less than 60% mortality.

An example of the rapid development of cross-resistance that can occur in an area of intensive agricultrual spraying was reported by Lowe **et al.**, (1980). Georghiou (1972) reported that **A. albimanus** in El Salvador was susceptible to the larvicide temephos with a LC_{50} of 0.005 ppm. On this basis, the compound was aerially applied to reduce populations in 1976 and 1977 as part of a sterile male release programme. Field bioassays conducted at the time showed continued susceptibility, but prior to the application in 1978, laboratory bioassays on field populations indicated that a 168-fold resistance had developed. The reason for the rapid development of resistance is not clear, however it was suggested that the timing of the application may have been important. Every year, from August to December, cotton in this area was intensively sprayed. The first aerial application of Abate^{R} (temephos) was carried out in March 1976 and in July 1977, 6 months after the last spray for cotton. In January, 1978, resistance was detected immediately after the end of the cotton spraying season. Moderate control was achieved in 1976 and 1977 because the appliction was not made immediately after the end of the cotton spraying season, whereas in 1978 it was.

At present, it is interesting to observe that in this area of El Salvador cotton is no longer grown and that temephos is now being used again (Frederickson, 1987, personal communication).

While the most serious problems of insecticide resistance have occurred in the Pacific Coast of Central America, the problem is not confined to this area. In Colombia there are 3 principal malaria vectors: **A. darlingi**, **A. nuneztovari** and **A. albimanus**. Of the three, only **A. albimanus** has been found to exhibit resistance to DDT and only in the North along the border with Panama. As a result, DDT is still extensively used in the house spraying programme. In Ecuador, **A. albimanus**, **A. punctimaculata** and **A. pseudopunctipennis** are the major vectors of malaria. In 1959 resistance to dieldrin was discovered in **A. albimanus** in an agricultural area. However, to date all 3 species remain susceptible to organophosphates. Some tolerance to DDT has been noted in **A. albimanus** and **A. punctimaculata**.

The development of resistance in **A. albimanus** has been found to occur mainly in cotton production areas. In the 1960s cotton production in the Americas peaked and then began to decline dramatically. The reason for this decline was due to the high production costs, requirement of heavy pesticide application and a lower price for cotton. When cotton was replaced by sugar cane, the pressure on mosquitos was reduced as considerably less spraying was performed. In areas where cotton was replaced by rice the problem continues. As with cotton, control of rice pests is dependent on insecticides. The heavy use of the carbamate carbaryl and also methyl parathion have caused a rise in resistance to carbamates and organosphosphate insecticides. In southern Chiapas, cotton has been replaced by soya but there are signs of some diversification of the crops in that more mangos and citrus are being planted. The trend away from monocultures is promising if it continues since this will create a more diversified agricultural ecosystem which will hinder the build up of large pest populations.

Many countries have prohibited the use of organochlorine insecticides such as DDT, aldrin, endrin, chlorodane, BHC etc. and have placed a high priority on the development of integrated control strategies. This trend should be encouraged and supported by countries which have developed comprehensive control programmes to combat their own pest problems.

11. INTRODUCTION OF IRRIGATION IN BURKINA FASO AND ITS EFFECT ON MALARIA TRANSMISSION

P. Carnevale[1] and V. Robert[2]

Introduction

Rice fields can provide appropriate breeding sites for important vectors of malaria, arboviruses , filariases, etc. (Surtees, 1970; Mitchell, 1977; Yelnik **et al.**, 1982; Mogi **et al.**, 1984) and there has been a general mosquito problem in all the areas where rice growing has been introduced (Choumkov, 1983). It is estimated that one quarter of the anopheline species that are vectors of malaria are able to breed in rice fields (Harwood and James, 1979), but the proliferation of anopheline mosquitos that almost inevitably follows introduction of rice growing (Webbe, 1961) does not necessarily result in a recrudescence of malaria. In northern Cameroon, for example, malaria has regressed sharply in the rice-growing area of Yagoua and has declined from a hyperendemic to a mesoendemic level (Couprié **et al.**, 1985) following improvements in the standard of living and increased use of antimalarial drugs. In the Ruzizi plain of Burundi, on the other hand, there has been an alarming increase in malaria with the extension of rice-growing (Coosemans, 1985).

The present study deals mainly with malaria and investigates its particular characteristics in the rice-growing area of the Kou Valley, Burkina Faso, where malaria is hyperendemic (Choumara **et al.**, 1959).

Historical background

Since independence, successive governments of Burkina Faso have attempted to develop the production of rice for local consumption and to reduce the country's dependence on foreign supplies. In 1965, the Government of Taiwan established an agricultural mission in Burkina Faso, and started pilot rice-growing projects at Boulbi (76 hectares) and at Louda (112 hectares), which were handed over to the Government of Burkina Faso in 1970. The project in the Kou Valley, launched in 1967, was initially planned to irrigate 1 260 hectares, with the settlement of 1 200 families (i.e. 15 000 settlers). Work was halted in 1973, but then resumed in 1974 by specialists from the People's Republic of China, who handed over the project to the Government of Burkina Faso on 30 December 1975. Since then, this rice-growing area in the Kou Valley has been managed by the Organisme Régional de Développement (ORD) des Hauts-Bassins (Regional Development Board for the Upper Volta Basins) and the Commune of Bobo-Dioulasso.

Topographical and social organization

* The geographical setting

The Kou Valley agricultural area is situated some 25 km north of Bobo-Dioulasso, on the road between Bobo and Mopti. This region consists of an old plateau of

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sandstone and schist, in which there are many poorly drained and swampy hollows. The irrigation area is in a flood plain of 97 100 hectares, of which 2300 are suitable for cultivation.

The original vegetation is the (shrub) savanna type, with shea and West African locust-bean trees, and has considerably deteriorated as a result of human activity.

The climate is of the Sudano-sahelian type, with a rainy season from May to October (1000 mm/year) and a dry season from November to April. Mean temperatures are 27-29°C, with a mean maximum of 37° in April and a mean minimum of 12° C in December.

* Irrigation: the engineering structures and water management

The hydraulic works involve irrigation and drainage networks (Gilbert, 1982). The irrigation network comprises:

- a water-supply point, on the River Kou, 11 km from the rice growing area, near the village of Diaradougou;

- a concrete-lined feeder canal, 11 km long, with a discharge rate of 3.2 m^3/s; the gradient is 1 cm/100 m, which permits irrigation solely by gravity. The water is distributed to the rice paddies by a system of sluices and canals;

- a concrete-lined main canal, 11 km long, which is a continuation of the feeder canal;

- secondary (82 km) and tertiary concrete-lined open canals. The tertiary canals each supply 12 hectares;

- unlined distribution channels lead out of the tertiary canals at intervals of a hundred meters, irrigating the paddies (25 m x 20 m) which are separated by earthen bunds covered with grass, with a base of 0.80 to 1 m 20.

The drainage network (98 km of unlined channels) runs parallel to the irrigation network; it consists of ditches (40 cm) at the lowest point of each paddy which collect the excess water. In each paddy, the difference in level between the highest and lowest points is about 10-15 cm. These ditches run to the drainage channels, which empty into the main drains to discharge into the Bama pool (about 200 hectares), which joins the River Kou downstream from the rice-growing area.

A water distribution schedule is drawn up fortnightly by the head of the irrigation service and the opening of the sluices is the responsibility of the irrigation "guard". But the sluices are frequently opened for longer or more often than planned, which wastes water and creates a serious drainage problem. This is further complicated by the dense growth of aquatic vegetation in the unlined channels, which limits the discharge of water and creates breeding sites for mosquitos. Hence, all the ditches in the irrigation network must be cleaned once a year using excavators in the main and secondary channels and scything for the smaller channels and the drains.

* The rice-growing cycle

In the Kou Valley there are two crops a year of rice grown under irrigation:

- a first "out-of-season crop", grown during the dry season from January to May

- a second crop, during the rainy season from June to November.

Sowing is done under 2 cm of water, and as soon as the seeds sprout, the seedlings are submerged in 6-10 cm of water for at least eight days. This phase provides water bodies ideal for the breeding of **A. gambiae**.

After 15 to 20 days in the rainy season, or 30-40 days in the dry, cool season, the seedlings are sufficiently robust for transplanting. The ground is flooded and levelled, and transplanting proceeds at about 1 hectare/week in muddy soil under shallow water. The depth of the water is 5cm after transplanting and is increased to 10 to 25 cm as the rice develops. Throughout this period, therefore, water is permanently available for the development of mosquito larvae, while in the neighbouring savanna there are very few larval breeding sites.

However, when the plants begin to extend, their shadow on the surface of the water inhibits the development of **A. gambiae**, but favours other species, such as **A. pharoensis** and later **A. coustani**. Even when the rice is cut and the paddies are drained about 135 days after sowing there are always areas that provide favourable conditions for mosquito breeding because the paddies are not drained simultaneously. For some time after the rice harvest, many holes remain and the residual paddles exposed to the sun once again constitute temporary breeding sites for **Anopheles gambiae**.

* The social and health structures

The development of rice growing in the Kou Valley has three major objectives (Pale and Oudraogo, 1985);

(a) to develop domestic rice production and to cut back on imports;

(b) to raise the wages and standard of living of agricultural workers;

(c) and, consequently, to reduce immigration to Côte d'Ivoire.

The area was settled by providing incentives for the transfer of about 10 000 volunteers, mainly from the Mossi Plateau, who were settled between 1970 and 1974 in 6 villages VK1 to VK6) established by the project. These villages cluster around the traditional village of Bama, whose population is of the Bobo ethnic group.

The social structure is clearly defined: 1 hectare per family (this may be expanded up to 3 hectares), compulsory membership of the cooperative, which is the monopoly rice marketing organization and provides widespread and permanent supervision; social facilities: 1 market, 1 post office, 1 police station, 2 dispensaries, 1 school, 1 maternity clinic and 1 community health centre.

A primary health care project was started in 1981-1982. The health workers comprise: 2 nurses and their assistants, 1 ambulant health worker, 8 community health promoters, 2 community health coordinators, 4 traditional birth attendants and 2 midwives, 8 primary health workers of the "secouriste" or emergency type in each village, who give first-aid and also issue aspirin and Nivaquine^R for attacks of fever. The ambulant health worker organizes meetings and talks with the women in each village, emphasizing problems of hygiene and parasitic diseases such as schistosomiasis, intestinal parasitoses (Pazart, pers.com.).

The community health promoters are mainly concerned with the problem of malnutrition, which is more serious than might be expected in this agricultural area. The nurse at Bama receives regular reports from all these health workers and makes a monthly report to the departmental officer-in-charge at Bobo-Dioulasso.

Health problems - mosquitos - malaria

* Status of malaria prior to introduction of antimalarials

Weekly chemoprophylaxis of children aged from 0 to 14 (10 mg/kg chloroquine) was introduced in 1981 and continued in 1982 in villages VK1, 4 and 6. Routine

administration of chemotherapy for attacks of fever was introduced over the same period (same product, same single dose of 10/mg/kg) in VK2, 3 and 5.

The traditional village, Bama, served as a control. The same control strategy was carried out in five savanna villages where chemoprophylaxis was given in two (Desso, Koro), chemotherapy in two (Baré, Toukoro), and Soumousso was taken as a control

Four malaria surveys (January-April-July-October) carried out in the "base" year, i.e., before the introduction of chloroquine (Baudon **et al.**, 1981) revealed seven points that should be noted:

1. In the savanna area, the malaria situation varied greatly from one village to another, depending on local ecological conditions (table 1).

Table 1. Mean annual index of endemicity (I.E.) (= parasite incidence in children aged 2-9) in the savanna area (A) and the rice-growing area (B).

A - Savanna

Villages ▷	Soumousso	Baré	Desso	Koro	Toukoro	Total
I.E.	61.7% (n=115)	73.6% (n=174)	60.3% (n=204)	61.5% (n=156)	54.8% (n=168)	64.4% (n=817)

B - Rice-growing

Villages ▷	VK1	VK2	VK3	VK4	VK5	VK6	Total VK	Bama	Overall Total
I.E.	32.9% (n=349)	47.5% (n=181)	50.8% (n=226)	37.3% (n=110)	43.5% (n=154)	46.5% (n=245)	42.8% (n=1305)	50.8% (n=240)	44.0% (n=1545)

2. Contrary to what was expected, however, there was a certain lack of consistency in this parameter, which was lower in the villages of the rice-growing area:

The annual index of endemicity appears to be highest:

- in the traditional villages established before the irrigation developments;
- in the villages on the border between the rice fields and the savanna (VK5 and 6);
- in the two villages in the centre (VK2 and 3);

The index appears to be lowest:

- in the village at the centre of the rice field (VK4);
- in the village in which the major services (school, management, dispensary etc) are located (VK1).

3. With a mean index of endemicity of 43%, the rice-growing area may be considered mesoendemic, whereas the savanna area, with an index of 62%, is hyperendemic.

4. With the exception of one survey (July), the parasite levels found in the rice growing area were always significantly <u>lower</u> the those found in the savanna area (table 2).

Table 2. Comparison of parasite incidence in rice-growing (VK) vs. non-rice-growing (savanna) areas.

▽Biotope / Time ▷	January (dry season)	April (dry season)	July (rainy season)	October (end of rainy season)
VK	44.5% (n=348)	36.2% (n=268)	55.5% (n=335)	33.9% (n=354)
Savanna	60.5% (n=215)	76.7% (n=215)	51.3% (n=154)	58.4% (n=233)

5. In all age groups investigated, the parasite incidence found in the rice-growing area was <u>lower</u> than in the savanna area.

6. This lower level of incidence in the rice-growing area was also indicated by lower spleen rates (which reflect immunity) and gametocyte rates (which reflect man-mosquito infectivity) than in the savanna.

7. Mean parasite density rates, however, were similar in the two biotopes. This means that parasite incidence may be lower in the rice fields, but infected children have, on average, parasite loads of a similar level to those in the savanna.

* <u>Main results of specific control measures</u>

Analysis of the effects of the chloroquine prophylaxis (C.P.) or therapy (C.T.) administered for two years (Baudon **et al.**, 1984) shows five important points:

1. Throughout the period of the survey, the general levels of endemicity recorded in the rice-growing area remained lower than those recorded in the savanna, although patterns of seasonal variation were similar.

2. Chemoprophylaxis was followed by a significant fall in parasite incidence in both the rice-growing and the savanna areas, (from 38% to 16% in the rice-growing area; from 61% to 29% in the savanna).

3. In spite of variations in incidence from one village to another these indices regressed steadily in the rice-growing area throughout the period of the programme which points to good overall social and health management of the population. In the savanna area, however, preventive treatment was carried out regularly only in the first year. Rising levels became apparent in the second year, indicating some lack of supervision in these villages and resulting in widely differing levels of success in the introduction of chloroquine. Chemotherapy had no significant effect on parasite incidence either in the savanna or in the rice-growing area.

Table 3. The effects of the introduction of chloroquine on parasite incidence in rice-growing and non-rice growing areas over the period 1980-1982

Year	1980		1981		1982	
Area ▷ / ▽ Villages	Rice field	Savanna	Rice field	Savanna	Rice field	Savanna
Control	50.8% (n=240)	61.7% (n=115)	43.8% (n=297)	42.6% (n=112)	36.3% (n=273)	48.8% (n=160)
CP	38.4% (n=704)	60.8% (n=360)	16.2% (n=732)	29.2% (n=352)	16.1% (n=745)	35.1% (n=45 6)
CT	47.9% (n=601)	64.3% (n=342)	34.6% (n=532)	54.9% (n=368)	33.7% (n=655)	58.2% (n=421)

4. Although the village of Bama was not officially covered by the programme for the introduction of chloroquine, there was a steady fall in the rate of endemicity (51%, 44%, 36%). This might be attributed, partly , to a rise in the amount of chloroquine in general circulation and an increase in the number of medical workers in the rice-growing areas as compared with the villages in the neighbouring savanna area.

5. The maintenance of relatively low parasite rates in the Kou Valley, by means of the preventive and curative administration of chloroquine by village health workers, has shown the potential of this method of malaria control in areas with a properly working system of social and health supervision. In the traditional villages of the savanna, on the other hand, it became clear that it was only feasible in practice to treat attacks of fever in the context of a campaign to reduce malaria morbidity using specially trained primary health workers.

* Entomological data in the rice-growing area

Studies of nocturnal man-biting mosquitos were carried out in the 12 villages of the project simultaneously with the drug treatment campaign. (Hervy **et al.**, 1980, 1981, 1982; Carnevale **et al.**, 1983). Analysis of the results obtained in 1981 (Hervy **et al.**, **loc. cit.**) reveals four major points of interest:

1. Mosquito vector populations

In the rice-growing area the vector population consists mainly of **A. gambiae** s.l., whereas in the savanna **A. gambiae** and **A. funestus** are found in similar proportions and succeed each other in the classic sequence: maximum numbers of **A. gambiae** from June to August and of **A. funestus** from August to October.

2. Intensity of transmission

The mean annual biting density of **A. gambiae** in the rice fields is 6 times higher than in the savanna, whereas that of **A. funestus** is about 2 times less, and that of **A. nili** 5 times less. The infectivity rate of **A. gambiae** is 12 times less in the rice-growing area than in the savanna. The rate is only 2 times less for **A. funestus**,

Table 4. Composition of **Anopheles** populations in the rice-growing (VK) and non rice-growing (Savanna) areas near Bobo-Dioulasso, Burkina Faso

	Rice-growing area				Savanna			
	A. gambiae	**A. funestus**	**A. nili**	Total	**A. gambiae**	**A. funestus**	**A. nili**	Total
Density (ma)	45.1	4.8	0.4	50.3	7.4	8.1	2.0	17.5
Infectivity (s)	0.27%	0.86%	1.25%	0.36%	3.30%	1.87%	1.18%	2.40%
	(n=6364)	(n=1047)	(n=80)	(n=7491	(n=1210)	(n=1279)	(n=337)	(n=2826)
Daily rate of innoculation (h = ma.s)	0.12	0.041	0.005	0.18	0.24	0.15	0.024	0.42

(ma = mean number of bites/person/night; s = percentage of dissected salivary glands presenting sporozoites)

while the sporozoite rate for **A. nili** is comparable. Thus, in spite of an overall density of malaria vectors which is 3 times as high as in the savanna, malaria transmission is 2.5 times less intense in the villages in the rice-growing area than in the neighbouring savanna villages.

3. Pattern of transmission

In the rice-growing area, the biting rate reaches a peak during the rainy season (90 bites/person/night) but it is also fairly high during the dry season (20 bites/ person/night in April-June). In contrast, the biting rate is very low in the savanna, where it only peaks in the later part of the rainy season (30 bites /person/night) when both **A. gambiae** and **A. funestus** are active.

In the rice-growing area, the pattern of transmission is distinctly bimodal, with two peaks: in May-June and in November (approximately one infected bite/person/week), coinciding with the two rice harvests. At the height of the rainy season, however, transmission is very low throughout the area (2.7 infected bites/person/month) although anopheline mosquito density is very high (2500 bites/person/month). In the savanna, transmission increases in the classical manner, (i.e., in proportion to anopheline vector density), during the rainy season and reaches a peak from August to October (almost one infected bite/person/night). The dynamics of malaria transmission are thus very different in the savanna and in the rice-growing area, where transmission appears to be clearly linked with the rice crop cycle. The dry season crop has an obvious influence, for the biting rate in April-May is 3 times higher than in the savanna and transmission is 5 times as high. Yet, paradoxically, during the rainy season, transmission is up to 10 times lower in the rice fields than in the savanna, in spite of the fact that density is 3 times as high.

4. Heterogeneity of situations

There is considerable heterogeneity in the intensity of transmission in the rice growing area, both in time and place. For example, the mean daily biting rates (ma) and infective biting rates (h) observed in 1982 in the villages in the Kou Valley (Carnevale **et al.**, 1983) were as shown in table 6. The same is shown for the savanna

Table 5. Mean daily biting rates (ma) and mean infective biting rates (h) recorded in rice-growing (VK) and non rice growing areas (savanna) near Bobo-Dioulasso, Burkina Faso.

	March	April	May	June	July	August	September	October	November
VK	= = = =		= = = =	= = =	= = = =		= = = = =	= = = = =	
ma:	7.7		22.8	21.2	92.2		76.2	40.4	
h:	0		0.16	0.17	0.11		0.09	0.25	
Savanna		= = = =	= = = = =	= = =		= = = =		= = = =	= = = =
ma:		5	8.3	20.9		32.7		32.6	5.4
h:		0.04	0.03	0.61		0.71		0.90	0.21

(= = = = survey period; ma and h: total for all vector species).

Table 6. Intensity of transmission of malaria in a rice growing area near Bobo-Dioulasso, Burkina Faso (1982)

Parameters	Villages VK1	VK2	VK3	VK4	VK5	VK6	Bama
ma	40.2	35.8	32.1	21.8	34.7	32.7	19.1
s	0.64% (n=1415)	0% (n=1260)	0.18% (n=1128)	0.26% (n=769)	0.41% (n=1226)	0.09% (n=1146)	0.74% (n=673)
h	0.25	0	0.06	0.056	0.14	0.03	0.14

(ma = average daily biting rates, h = average infective biting rate)

Table 7. Intensity of transmission of malaria in a non-rice-growing area near Bobo-Dioulasso, Burkina Faso (1982)

Villages ▷ / Parameters ▽	Toukouro	Koro	Desso	Baré	Soumousso
ma	10.4	10.5	22.9	2.95	18.4
s	1.36%	2.93%	1.72%	7.62%	5.86%
	(n=367)	(n=375)	(n=815)	(n=105)	(n=648)
h	0.14	0.31	0.39	0.22	0.08

Table 8. Intensity of transmission (as measured in average infective bites) in a number of villages in rice-growing (VK) and non-rice-growing (savanna) areas, in two consecutive years, 1981 and 1982

Year \ Village ▷	VK1	VK2	VK3	VK4	VK5	VK6	Bama
1981	0	0.06	0.17	0.055	0.10	0.15	0.48
1982	0.25	0	0.06	0.056	0.14	0.03	0.14

Year \ Village ▷	Koro	Desso	Baré	Toukoro	Soumousso
1981	0.47	0.57	0.25	0.21	0.55
1982	0.31	0.39	0.27	0.14	0.18

area in Table 7, where differences in the intensity of transmission recorded conform to the classical pattern, reflecting local ecological conditions. The same heterogeneity is found over time as shown in table 8: in the same village infectivity rates may greatly differ from one year to another.

The influence of macroclimatic fluctuations is thus clearly felt in all the villages, but whereas this was expected in the savanna, it seemed paradoxical that such heterogeneity of transmission should be found in the apparently uniform biotope of 1000 ha. of irrigated ricefields.

Study and analysis of the "epidemiological paradox" of the Kou Valley rice growing area

Four programmes were specifically developed to make a more thorough analysis of the apparent epidemiological paradox observed in the Kou Valley rice growing area.

1. Simultaneous studies of transmission in the rice-growing and savanna areas

A detailed entomological study of malaria transmission was undertaken simultaneously in two representative villages of the rice-growing area, VK4 and VK6, and 3 savanna villages (Dande, Tago, Kongodjan) with different ecological conditions (Robert **et al.**, 1985). Three points emerged clearly:

(a) anopheline biting rate: in the rice fields, the annual number of anopheline mosquito bites per person is about 13 - 14 000 and biting continues throughout the year. In the savanna, the people receive 1 500 to 7 500 anopheles bites, depending on the village, mainly during the rainy season,

(b) intensity and pattern of transmission: the rice field population received 50 infected bites a year and malaria transmission tends to follow a bi-modal pattern. This is such a high number of infective bites (Gazin **et al.**, 1985a,b) that no-one living in the growing area escapes malaria. Savanna-dwellers receive 50-250 infected bites, depending on the village, but transmission is always concentrated in the rainy season.

(c) regulation of adult mosquito populations: Study of **A. gambiae** collected on humans at night shows inverse correlation between levels of density and parity: when the density of females is highest, the number of parous females is lowest; conversely, density decreases when the number of nulliparous females increases. The mechanisms involved in this phenomenon are not known. Mean levels of parity among man-biting females in the rice growing area are very low (50% compared with 70% in the savanna) and this helps to explain why mean sporozoite rates are distinctly lower than in the savanna, being respectively 0.5% and 2-3%, (Robert **et al., loc.cit.**).

2. Cytogenetic studies of the **Anopheles gambiae** complex

The consistently low level of infectivity rates in **A. gambiae** populations in the rice growing area as compared with those in the savanna, suggested possible genetic differences between the two populations. A series of cytogentic studies (Robert **et al.**, 1986; Petrarca **et al.**, 1986a,b) has brought out five key points:

(a) **A. gambiae** and **A. arabiensis** are sympatric in the Bobo-Dioulasso area and occur with varying frequency depending on the local ecological conditions in the villages (Robert **et al.**, in press);

(b) **A. gambiae** is largely predominant in the area as a whole, but two chromosomal forms - "Mopti" and "savanna" - may be distinguished within this species;

(c) 97% of the **A. gambiae s.l.** caught at the centre of the rice field were of the Mopti cytotype; the savanna form is proportionally better represented at the edges than in the middle of the rice field;

(d) **A. arabiensis** is also found in greater numbers at the edge than in the middle of the rice growing area;

(e) the frequency of certain chromosome inversions may be related to transmission dynamics.

3. Species succession in the rice growing area

The succession of culicine species in the course of the rice cycle has been analysed, by monitoring the species composition of samples of larvae taken from different biotopes in the rice-growing area (Robert **et al.**, 1986b).

A. gambiae was the first species to develop during the rice cycle, and flourished from the irrigation of the rice paddies until the rice had extended sufficiently to throw a substantial shadow over the surface of the water. During the next phase (booting and heading of the rice), the larvae collected were mostly **A. pharoensis** (as found by Snow, 1983, in the Gambia), while **A. coustani s.l.** (= **A. ziemanni** in the Gambia) larvae were collected during the ripening of

the rice. **Anopheles gambiae** is thus well able to adapt to the conditions created by the cultivation of rice, unlike **A. funestus**, which is very rare in the rice-growing area.

4. Influence of insecticide-impregnated mosquito nets in reducing man/vector/parasite contact

The proliferation of different mosquito species (**Anopheles** and **Culex** and **Mansonia** and **Aedes**) in the Kou Valley is so great that the people try to protect themselves from mosquito bites by various means (coils, etc). Most people have developed the habit of sleeping under mosquito nets. Unfortunately there are often holes in the nets and they are thus no longer effective. To make mosquito nets more effective as a means of individual and family protection, they were impregnated with deltamethrin in VK4 (Carnevale **et al.**, 1986). A similar programme was undertaken simultaneously at Karankasso, a "traditional" savanna village, and multi-disciplinary evaluation of this programme is under way at the instigation and with the support of WHO. The first results appear to be very promising.

The use of insecticide impregnated mosquito nets has been perceived as an excellent means of combatting the mosquito nuisance and has been accepted by the people of VK4, particularly as they were already using mosquito nets and are also using insecticides (Decis^{R}) at certain stages of the rice cycle. The use of the two methods in association has therefore met with complete approval and there is a high level of involvement on the part of the village community.

Conclusions

The density of culicine and anopheline species in the Kou Valley rice growing area is extremely high. The anopheline mosquitos continue to bite throughout the year and in the rainy season they proliferate to the extent that people may receive as many as 150 **Anopheles gambiae** bites a night. When the major vector of human malaria is prevalent in such numbers, a catastrophic situation might be expected, with epidemic outbreaks amongst the new settlers from low transmission areas. Paradoxically, and very fortunately, this is not the case. Two of the many factors that help to account for this situation should be noted, and they are of an entomological and sociological order:

- In spite of the very high density of **A. gambiae**, transmission is relatively low (50 infected bites/person/year), i.e., three times lower than in the savanna villages. Nevertheless, this level of transmission is such that no one can escape malaria;

- social and health supervision in general appears to function well and access to health care and basic drugs is facilitated by the existing infrastructure. Nevertheless, this rice growing area in the Kou valley is more than "receptive" when the major vector is present in such quantities. Measures must therefore be envisaged at several levels to combat the potential risk of malaria, especially control of the disease through continuous improvement in diagnostic and general health services, and permanent vector control activities to reduce the frequency of man/mosquito contacts and the longevity of vectors.

12. ETHNIC FACTORS IN THE TRANSMISSION OF SLEEPING SICKNESS IN THE FOREST REGION OF CÔTE D'IVOIRE[1]

J. P. Hervouët[2] and C. Laveissière[3]

Introduction

This contribution is aimed at promoting a better understanding of social factors affecting the transmission of sleeping sickness and is in no sense addressing the biological aspects. It is concerned only with human geography and human ecology and does not imply the existence of possible adaptative characteristics among certain human groups to trypanosomiasis (sleeping sickness) or of a greater or lesser receptivity of certain ethnic groups to the parasite species causing the disease.

The production of coffee and cocoa as cash crops by small village undertakings has become predominant in the forest region of Côte d'Ivoire during the last half century. This economic and agricultural shift has been brought about by extensive use of "foreign" labour and by the settling of new ethnic groups. These profound economic changes have upset the forest environment in Côte d'Ivoire, but above all they have led to the emergence of new social groups, both indigenous and of foreign origin. In itself, this would have been of little relevance within the terms of reference of the study but for the fact that each social group is embodied in a specific and original spatial projection. This territorial expression of social characteristics may be completely independent of other human groups or, conversely, it may result in the spatial overlapping of several interpretations of the environment.

The considerable transformations brought about in the forest environment by these new types of development have contributed to quantitative and qualitative changes in the tsetse fly populations, vectors of sleeping sickness. However, the spatial patterns of behaviour of the individuals forming the production groups result in man/vector contacts that carry the threat of transmission, and of the possible creation of epidemiologically dangerous situations.

Emigration and changes in settlement patterns

The introduction and development of coffee and cocoa as cash crops in the forest region of Côte d'Ivoire, has required a supply of "foreign" labour. The members of this temporary and semi-permanent population have, in considerable numbers, succeeded in acquiring land, thereby augmenting the number of planters. They are almost exclusively people from the northern savannas: some of them nationals of Côte d'Ivoire, but the majority from Mali and Burkino Faso (mainly Mossi). Another group that has settled in large numbers is the Baoulé, nationals of Côte d'Ivoire from the forest-savanna transition zone, who are great pioneers. Unlike the ethnic groups from further north, however, they have made little or no labour contribution to the indigenous people.

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* Replacement of the original population by the arrivals

Everywhere in the farming areas, even in the South East, the "foreign" population, whether nationals of Côte d'Ivoire or not, has overtaken in number the indigenous population, although exact figures have not always been recorded.

In 1983, the Vavoua trypanosomiasis "focus" in the centre and West of Côte d'Ivoire had 10 325 inhabitants, of whom 1 650 (16%) were of local origin, the Kouya and the Goura, 1 300 (12.5%) were Baoulé and 7 375 (71.4%) were Mossi. A little further west on the Lobo, the indigenous people, the Niedeboua, constituted only 18.5% of the total population, as against 26.2% for the Baoulé and 55.3% for peoples from the northern savanas, predominantly Mossi.

Only the groups in the South-East of the country, the Agni, and in the far West, the Yorouba, appeared to have kept control of the greater part of crop production. The Yorouba work the land themselves, while the Agni employ a very large labour force, especially on a "share-cropping" basis: there are more than four share-croppers to every planter in the Abengourou region, which was the centre of a sleeping sickness epidemic in the early 1960s.

* Clearly differentiated social and occupational categories

A cursory glance at the population figures by age and ethnic group (table 1) reveals clear distinctions between groups. While the Baoulé population appears to be balanced, the same cannot be said of the Mossi or the indigenous peoples. Among the former, in contrast to the latter, the productive age groups are predominant, whereas the migration of young adults to the towns is a feature of the indigenous peoples, and the population is an old one. These are not, however, merely differences between ethnic groups. They are also very clearly apparent in socio-economic status, the extreme case being labourers and planters' assistants, 68.5% of whom are individuals between 15 and 40 years old, mostly unmarried. There are only 30 women to every 100 men in this group, which constitutes quite a large labour force.

Table 1. Population structure by age group, ethnic group and socio-economic categories

	0 - 15 years	15 - 40 years	Over 40 years	Total
Mossi planters' assistants and labourers	234	685	91	1000
Mossi Lobo	399	586	15	1000
Baoulé	509	408	83	1000
Mossi, farming at Vavoua	592	325	83	1000
Goura - Kouya	334	346	320	1000
Niedeboua	534	293	163	1000

* Different situations in relation to production

Just as the populations differ in structure, they also differ in relation to the size of their agricultural holdings (table 2).

Table 2. Size of holdings at Daniafla (in hectares)

Crop	Mossi	Baoulé	Niedeboua total	Niedeboua direct exploitation
Coffee	3.16	1.27	7.0	0.3
Cocoa	3.71	9.19	2.6	2.0
Food stuffs	0.16	0.64	1.07	1.07

The same differences between ethnic groups are also to be found in the Vavoua focus where the indigenous Goura directly cultivate only 2.97 hectares of coffee and cocoa on average. The only noteworthy difference between the two zones is that cocoa accounts for less than 10% of the area under cultivation at Vavoua. This is important only in so far as the number of days of work required to tend and harvest cocoa is far less than required for coffee. On average, there are 8.7 people to a Mossi holding, 10.2 to a Baoulé holding and 10.5 to a holding of the indigenous peoples. However, although this population is smaller than the populations of the other groups, the labour force is greater because there are more adults between the ages of 15 and 50: 3.3 men and 1.8 women as against respectively 2.12 and 2.14 among the Baoulé and 1.4 and 2.23 among the peoples of local origin.

As a general rule an indigenous farmer can work only a small part of his land. In most instances he hands over plots that have been worked for more than 5 years, and that no longer produce foodstuffs, to Mossi on a share-cropping basis. Consequently his volume of agricultural work is considerably reduced.

Conversely, the holding is directly worked by the Baoulé, as it is by the Sudanese, and some labour is employed: 0.5 of a worker on Mossi holdings, 1.5 on Baoulé holdings (the holdings of the indigenous people would require more than 4 employees). Under these conditions, the Baoulé are one labour unit short at harvest time, whereas the Mossi have one labour unit to spare, which is employed among the indigenous peoples. The "traditional" indigenous space therefore emerges as an open social field that has been conducive to the arrival and subsequently the establishment of foreign groups. In addition, the low density of the forest populations has been conducive to the colonisation of their space by immigrants, who have now become principally responsible for shaping the landscape.

Spatial projections of human groups

There are significant differences in the occupation of space by the various ethnic groups present in the forest.

* Characteristic Landscapes

As the various human groups occupy space, they produce different landscapes characteristic of their ethnic groups and of their relationships to the environment.

The indigenous peoples give rise to landscapes in which the land is greatly divided up and the main vegetation is primary forest and forest re-growth. Conversely, among the immigrant Baoulé and the Mossi, shrub crops occupy most of the space between the fallows and the food crops. In addition, the fields of the indigenous peoples are always located close to the bottomlands of main rivers, where rice is grown, the Sudanese are confined to the dryer areas between adjacent streams while the Baoulé occupy an intermediate position on the tributaries of the major watercourses.

Almost all the indigenous peoples (93%) live in villages close to the bottomlands. The Baoulé prefer to live in hamlets with between 50 and 400 inhabitants (63%), whereas the Mossi and other Sudanese tend to live in small settlements scattered around within the plantations. In general the Baoulé site their dwellings on the edges of their spatially well delineated plantations or along the edge of the enclosed savanas, and the lands of each holding have a single tenant. Conversely, the Sudanese live within their agricultural land or in their own sectors of otherwise indigenous villages. At Vavoua they have also created their own villages. Like those of the indigenous peoples, their holdings are split up into 2, 3 or more scattered blocks often more than 10 km apart.

Thus, the Mossi and to a lesser extent the indigenous peoples are obliged to make frequent long journeys because of the spatial pattern of their holdings and the siting of their dwellings, whereas the Baoulé concentrate all the elements of their local "living space" into a small area.

* Contrasting social spaces

One of the main characteristics of Baoulé spaces is their social isolation and the absence of relations between them and the other ethnic groups. In contrast, this is not at all the case for the Mossi immigrant community.

The Baoulé keep their relations with the indigenous peoples to the strict minimum and courtesy calls are rare. The latter have often lost all rights over the existing palm trees on the land on which they have granted concessions, and for that reason scarcely ever penetrate into Baoulé space. The Baoulé, for their part, have very few contacts with the indigenous space, avoid its villages and markets, and trade within their own settlements. Furthermore, neighbouring Baoulé settlements do not maintain close relationships unless they are occupied by people from the same tribe or the same village. Real tribal frontiers exist between the various social communities, the various plantations of the same settlement are themselves quite separate and the tracks leading to them, which are usually dead-ended, do not link up and therefore serve to isolate the plantations socially.

The Mossi, like most Sudanese peoples, have preserved close relationships with the indigenous peoples who have granted them the land. They often share a part of the villages of these peoples and actively contribute to the markets held in them and by working the greater part of their plantations, they maintain employee-employer relationships in addition to their friendly dealings. Furthermore, as the forest available for sale becomes less and less, even to the point of total disappearance, the indigenous people, in need of money, are beginning to grant concessions on parts of their own plantations within the village lands. The result is that the Sudanese constantly pass through the indigenous space. Conversely, the autochthonous peoples have retained some rights on the palm trees in Mossi plantations and they therefore enter those plantations to collect bangui (palm wine).

Unlike the spaces of the Baoulé, which are socially greatly divided up and individualized, the spaces of the indigenous peoples and the Sudanese appear equally open and collective, and overlap. That basic difference is all the stronger because the "Mossi" space does not have tribal frontiers between the communities and any "regional" feeling that may exist is not strong enough to result in the division of the space.

These differences of attitude have an essential bearing on the spatial behaviour of groups of people and, consequently, on their types of contact with the sleeping sickness vector.

Human behaviour and sleeping sickness

Primary forests do not offer the right conditions for the transmission of human trypanosomiasis. It is agricultural activity that makes circulation of the parasite possible, through the increased integration of a human element in the environment.

* Modification of tsetse fly populations

The replacement of the forest by shrub plantations, has profoundly modified the distribution of the various tsetse fly species. **Glossina palpalis**, the only regional vector of sleeping sickness, which is a particularly adaptable species with a tendency to be anthropophilic, has spread in all the areas cultivated by man. Fly populations have remained plentiful in the woodlands along the water courses; they have proliferated around villages on account of the presence of pigs, the tsetse fly's preferred source of food, and they have occupied all biotopes modified by human activity. The vector of trypanosomiasis is at its most numerous in the botanically varied village lands with their multiple ecotones, but in no part of the forest plantation environment is man really safe from insect bites. The risk of transmission appears to be omnipresent throughout the space occupied by man, although at varying levels, depending on the environments under consideration. Although less important than in the savanna, water remains a far from negligible factor so that, whatever the dominant shrub crop, the edges of the plantations and the forest, the footpaths running along them, and the water points would appear to be the most dangerous zones.

* Man and the parasite

At the local level in the plantation zone, greatly differing levels of prevalence of trypanosomiasis are to be found among ethnic groups sharing the same area and also among the various social and occupational categories within these groups. This is not explainable by the botanical or entomological data.

In the Vavoua trypanosomiasis focus, between 1981 and 1983, prevalence was ten times greater among the Mossi than among the Baoulé and at least twice as great as among the indigenous peoples. In the Daniafla region, during the same period, prevalence was respectively 0.20 among the Mossi, 0.13 among the Baoulé and 0.07 among the indigenous peoples. The same inter-ethnic difference was found once again in the 1940s in the Bouaflé focus and in the 1960s in the Abengourou focus.

Incidence among the Mossi in 1981 was twice as great among village dwellers as compared with individuals living in the settlements within the plantations, from which 75% of the trypanosomiasis cases came. The age group most affected was that between 15 and 40 years, in which men were significantly more affected than women. In addition, 42% of the patients were temporary labourers, a group representing only 20% of the resident population. Sufferers were primarily individuals of working age in the plantations who were members of groups of people in which the parasite was able to circulate on a vast scale.

* Ethnic group characteristics and health status of its members

Frequent close contacts between man and tsetse fly are essential to the transmission of sleeping sickness. Population densities are important at that level because they influence the presence of other sources of food for the tsetse fly. Nevertheless, there are no significant differences of population density in the various ethnic spaces. However, there are considerable dissimilarities to be seen between the ethnic groups in the contact between man and the vector, which is weakest for the Baoulé, twice as great in the indigenous lands and five times as great among the Sudanese. As, moreover, the indigenous peoples entrust the working of their plantations to Sudanese, it may be assumed that a considerable number of the blood meals taken in those lands are taken on members of the Mossi.

By virtue of their frequent movements for social purposes or for work, the Mossi create what is apparently a raised density and are thus a particular prey of tsetse flies. Furthermore, the indigenous peoples and the Baoulé have wells and pumps in their villages or hamlets; consequently, they do not have to go to a water point to obtain supplies. Conversely, the Sudanese obtain their water either in the indigenous village or from a communal water point sunk in humid, forested bottomland, where the density of **G. palpalis** is always considerable. In that case, not only is contact between man and the tsetse fly an almost daily occurrence, but there is considerable mixing of the tsetse fly population and the human population in which carriers of the parasites may be present. The Sudanese thus create conditions conducive to the transmission of sleeping sickness by the apparently raised human densities they generate.

Taken together, contacts between man and the tsetse fly, population movements within activity areas, and the possibilities of introducing the parasite account for the risks run by the different social categories of the various ethnic groups.The "closed" system of the occupation of space among the Baoulé provides relative protection for them against the disease. Should the parasite be introduced into the environment, it is able to circulate only within the production unit occupying that space.

Conversely, the Mossi, and especially the labourers among them, are the most exposed group because they move around a great deal in a high risk, socially open environment in which the heavy mixing of the various population levels and numerous tsetse flies enables the parasite to circulate if introduced. Consequently, the trypanosome is able to circulate by virtue of "ethnic" behaviour no longer at the level of the production unit, but at the level of the entire ethnic group. Thus, the social and spatial behaviour of individuals permits maximum spread of the parasite within a large human space that may exceed the limits of the ethnic group because of the spatial overlapping of areas of cultivation between the Mossi and the indigenous peoples.

Populations may thus become seriously infected when their patterns of occupation of space enable the parasite to circulate to an extensive human group.

Conclusion

The transmission and spread of sleeping sickness in a forest plantation zone is far more dependent on the social and spatial behaviour of human groups than on the mere presence of tsetse flies which, while essential, is not in itself sufficient. It is the behaviour of human groups that determines the creation of epidemiologically dangerous situations.

There are clear implications here for the control of sleeping sickness and they prompt the suggestion that responsibility should be shared between the biomedical sector and development authorities concerned with land use.

Transition from coffee growing to cocoa growing may permit a reduction in contact between man and the tsetse fly in established plantations, as may the creation of homogeneous landscapes and the reduction of strips of uncultivated lands. The social and spatial behaviour of people is, however, likely to remain unaltered, with the result that relationships between man and the fly will continue to pose a risk. Only a vigorous plan for the development of the botanical environment and the infrastructure can provide hope of a solution to the problem of trypanosomiasis. Such a project would involve:

- the regrouping of all populations into hamlets with their own wells and boreholes;
- the control of vegetation and strips of uncultivated land;
- the spacial regrouping of plantations (possibly reallocation)

Lastly, it is essential for the various survey services concerned to be in a position to intervene rapidly. All this would, quite obviously, be conducive to and support the essential tsetse fly control operations to be carried out by the rural communities.

13. TRENDS IN IRRIGATION DEVELOPMENT AND THEIR IMPLICATIONS FOR VECTOR-BORNE DISEASE CONTROL STRATEGIES

C.L. Abernethy[1]

Introduction

The second half of the 1980s may well be a turning point in global agricultural policies. The previous decade was dominated by the growth of large surpluses of production in North America and in Europe. More recently, the grain production of South and East Asia, largely grown on irrigated land, has similarly increased. It has risen substantially faster than the population growth rate, and some countries of that region which were formerly persistent importers of grain, now face the different problems of identifying export markets for grain surpluses.

The implications for irrigation development of this relatively new situation remain uncertain. Initially, the rise of world-wide agricultural production levels has caused a slowing down of the rate of new irrigation developments. It is difficult to predict how long this phase will last, and there are (and will continue to be) substantial regional differences.

However, it seems reasonable to expect that the trends which we can currently observe will persist for some years yet, and they carry a number of implications for those concerned with the linkages between irrigation and public health. In particular, we should expect that the focus of interest in developing country irrigation will be on improving the performance of systems that already exist, rather than on constructing new ones.

In this paper we try to interpret the significance of these trends, and to see whether they mean that efforts for the control of vector-borne diseases should take fresh directions.

World trends in food production

Figure 1 shows how agricultural production has been increasing in the past two decades in some of the world's major regions. World-wide we have seen an increase of about 61%, or some 2.5% per year, in the period 1965-84. Although the over-production in the European Community and North America are well known, the figure shows that it is in Asia that the greatest growth rate (3.45%/year) has been achieved. Latin America and Africa have also shown significant increases of total agricultural production during this time.

But, although Asia and Latin America have achieved rates of increase greater than the world average, the developing countries have also had to deal with population growth rates that have persistently exceeded world averages. So, from the point of view of national planning and agricultural policy, it is more relevant to consider Figure 2, which shows the trends of agricultural production per person.

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Figure 2 illustrates some salient differences. It shows that the three continents of the "developing" world have been performing quite differently. In Asia, especially in recent years, agricultural production per person has been moving ahead at rates that appear, by international standards, very satisfactory. Latin America, on the other hand, has a rather static record. Africa, in which the highest population growth rates have been combined with the slowest agricultural growth rates, has experienced a drastic decline in per capita levels.

Rates of irrigation development

Figure 3 shows the present extent of irrigated land in each of the three continents of the developing world. Figure 4 shows the rates at which these areas have increased.

The 1960s and 1970s were a period of rapid expansion of irrigation, world-wide. More recently, the pace of new development has noticeably slowed down. It seems reasonable to suppose that there are linkages between these and the previous diagrams. That is, the success of irrigation development and other agricultural policies in enhancing food production has contributed to the slowing down of investment in new irrigation systems. In Africa, the diagrams seem to suggest a complementary trend: there, the rate of new irrigation development seems to have been sustained for longer, perhaps because the need for increased production is still present, and indeed is becoming more acute.

Irrigation does not have the same national significance, nor even the same objectives, in all the developing countries. In South and East Asia it is an essential activity for the support of large populations at high densities, and its predominant purpose is production of food (usually rice or wheat). In 1984, 30.0% of all cultivated land in Asia was irrigated. This had risen from 22.3% in 1965: that is to say, Asia's relative dependence on irrigation was increasing throughout this period of improving **per capita** production. In several Asian countries (China, Korea, Japan, Pakistan) dependence on irrigation exceeds 45%. On the world scale, Asia (excluding the Soviet Union) accounts for 62.3% of all irrigated land, and for 56% of the modern additions to that.

In South America and in Africa, on the other hand, there is as yet relatively little irrigation: only 4.7% of the world's total is in Africa, and 3.6% in South America. These much lower rates of irrigation reflect different demographic situations, and lower population densities. On the whole, the non-irrigated food production capacity of these continents is technically adequate for their present populations, and the pressure to enhance this capacity by irrigation has not been by any means as strong as in Asia. Thus, in comparison with the Asian figure of 30.0% dependence on irrigation, in Africa the comparable figure is 5.6% and in South America 5.7%.

What should we infer from these facts about the likely future course of irrigation development? First, let us consider Asia, overwhelmingly the dominant area of irrigation in the world. The pace of expansion has slowed down sharply, as Figure 4 shows. The food situation of many countries is better than it used to be, and in several there is concern about the difficulty of finding export markets for agricultural surpluses. So it seems reasonable to expect that the rate of implementation of new projects in Asia will, in the foreseeable future, be much less than in the past. On the other hand, there has been a growing recognition in recent years that many irrigation projects are performing below their potential. This perception is causing an emphasis on strategies for improving the performance of the existing systems, rather than installing new ones.

In Africa, matters are likely to be somewhat different. Figure 2 shows the need for special concern about Africa's agricultural performance. Well-known recent drought events in the Sahel area and in southern Africa, and the hydrologists' and meteorologists' difficulty in predicting the persistence or recurrence of these events, have led to a greater emphasis upon food security. The Mediterranean countries, Somalia and Madagascar already have a high dependence on irrigation and, because of the high population growth rates, various other countries, led by Kenya, will soon exceed their capacity to grow their own food needs unirrigated.

Pressures of this kind probably mean that in Africa, and in some American nations (notably Brazil) the impetus to develop new irrigated land will persist, but, as figure 1 shows, the areas involved will still be small, in relation to the world irrigation scene.

Anticipated patterns of future development

If the main emphasis in irrigation investment and project planning is moving towards the improvement of performance of existing systems, we have to consider what modes of project we are likely to see, and what the implications (and opportunities) may be for those concerned with vector and disease control, or other environmental policies. The project strategies likely to be pursued, for the purpose of enhancing irrigation performance, will generally emphasise:

i rehabilitation and modernisation

ii improved management

Rehabilitation, in this context, means the restoration of dilapidated facilities, and modernisation implies some degree of more basic changes in the system; but projects will commonly contain something of each.

The management methods in developing-country irrigation have been perceived for some time as an area in need of attention: the establishing of the International Irrigation Management Institute is one response to this concern, and there are many other reflections of it. This is not an appropriate place in which to review all the strands in the management problem, nor to attempt predictions as to where it will lead us over the next decade. But it should be expected that there is going to be an increase of attention to the control of water distribution patterns, to the rewriting of operating procedures, to the study of what irrigation people (both farmers and agency officials) actually do in the field, and what constraints and logic govern their decisions and behaviour.

Accompanying all these trends there is likely to be a heightened interest in the social, financial and production implications of what we may call the devolution of authority within irrigation networks. This expression includes prominently the question of delegating certain operational processes and (perhaps) decision-making powers to organisations of farmers.

There are, at present, fewer signs to suggest that the basic technologies of irrigation will undergo dramatic change. In general, in Asia and Africa, although perhaps less in South America, we ought to expect continuation of surface flooding as the predominant mode of irrigation. There will no doubt be some gradual shift towards groundwater sources, especially as multiple demands begin to exhaust accessible river sources; but here again economic logic will play its part. The use of groundwater implies an energy cost, which in most countries falls upon the end user, the farmer. He may get in return the important benefit of personal control over the time and quantity

of water delivery, and he will value this benefit most highly in places where defective management conditions cause supplies from canal systems to be erratic and unreliable. Nevertheless cost is likely to restrain the replacement of river sources by groundwater.

These factors, which cause a low rate of adoption of new irrigation technologies in the developing countries, are somewhat unfortunate from the viewpoint of vector-borne disease control. Pumped and mechanized systems in general reduce the vector-sustaining environments, and also reduce human/water contact opportunities. But we should recognize that it is cost problems that limit the introduction of these technologies.

The scale of irrigation systems is also relevant to vector control policies, and to various other environmental policies. There is at present a climate of opinion that seems to favour rather smaller project units than in the past. The reasons for this are somewhat diffuse or varied, and the data on which opinions have to be based are often imprecise, especially in regard to very small systems. However, in Africa, particularly, there are good reasons for expecting that smallish schemes may predominate in the immediate future. These reasons include the generally low population densities (implying among other things thinner, more easily saturated, markets); perceptions of low performance in state or para-statal irrigation enterprises; less common occurrence of the physical conjunction of large rivers and large alluvial soil deposits.

In parts of Asia, too, governments are having more success nowadays in finding ways of targetting assistance towards rehabilitation of village-scale irrigation systems, which often (for example, in Sri Lanka or Tamil Nadu) are of considerable age and embody a wealth of traditional practices.

None of this should be taken to mean that large projects are out of fashion. The assisting of the very small scale has in practice been found rather difficult to achieve, and the assessment of benefits from such policies is often obscure. But the inference that we should draw (specifically in relation to vector control) seems to be that the amount of attention given to small and traditional systems will increase.

The weakening of cereal prices and markets, which can be traced primarily to the high levels of excess production in Europe and North America discussed in section 2, is encouraging crop diversification policies, especially diversification away from rice; but the general difficulty of identifying alternatives whose markets will not in turn be swiftly saturated makes the outcome of this quite uncertain.

Health and vector implications of current irrigation trends

We have tried above to identify some of the main features or tendencies that are becoming apparent in developing-country irrigation strategies : rehabilitation; management improvements; some favouring of smaller-scale units; some devolution of management towards the farmers; crop changes and diversification. We have also looked at the global geography of irrigation, noting that Asia has over five times as much irrigation as all the other developing regions together, and that there are reasons to expect a sharp drop in the rate of new Asian irrigation developments. What consequences should such trends have, in regard to strategy against vector-borne diseases?

We must bear in mind that these developments are occurring against a background of falling prices and weakening markets for agricultural products. This means that irrigation organisations everywhere are meeting budgetary difficulties and that any additional measures which are advocated (whether for public health objectives or any

other desirable purpose) are likely to be subjected to cost scrutiny. In other words, there is increasing need for demonstration and measurement of the benefits of alternative policies.

In the search for guidelines to combat vector-borne diseases, there has been a tendency to concentrate upon planning and design rather than operational considerations. For instance, in the WHO Manual on Environmental Management for Mosquito Control[2], a checklist on project planning measures covers 70 points of which only 13 are openly concerned with operation. If we are entering a period of comparatively few new systems, design guidelines will not get to the heart of the problem. The tendency to seek improved general management performance, which we have noted already, coincides well with the health objectives, and should provide an admirable opportunity for joint efforts of a multi-disciplinary kind. Many of the operational defects that contribute to sustaining vectors (for example, canal seepage; excessive and poorly measured canal deliveries to the field) are also those that have to be attacked in the interest of overall system performance goals.

On the other hand, there are still deficiencies of information about the health and vector impact of various necessary operational parameters. For example : we know that vector control is in general improved by having intermittent rather than continuous flow in canals. But the acceptable ranges of such parameters as the rate of drawdown of water level, the duration of dry periods and their frequency, are not always clear. Operators have to choose values of these parameters under a variety of constraints, which include those dictated by crop, soil, meteorology, and engineerng facilities, as well as by the farmers' labour situation and life-styles. In these circumstances, if the health-related considerations are to have due weight, it is important to the operator that he has rather specific, quantified, guidance. These and other aspects of the interaction of system operation with health still seem to require investigation.

Any increase of interest in small-scale development also carries implications for vector studies. It has been noted before that more attention has been given to large than small systems from the vector point of view, and the same is true of operational and management studies. The problem of how to secure vector control on small systems, where operation is likely to be at a sub-technical level and probably not in the domain of a public-sector agency, needs consideration. Public health education, regular screening, and similar preventive measures, seem of most relevance here.

Moves towards crop diversification will also carry health connotations, and these are not yet very clear as the changes are rather recent and not yet widespread. Changes in cropping will change the vector environment, and may well expose populations to different levels of risk. Since one of the changes most discussed at the present - diversification away from rice - seems to imply reduced levels of water use and of standing water in fields, it could make environments less satisfactory to vectors. But many other sorts of change should be anticipated as crop choices are made more responsive to demand as expressed through markets.

Some suggested responses to the anticipated trends

Irrigation is generally undertaken to promote public health through increasing levels of nutrition. In the food-producing South or East Asian systems or in Egypt this linkage is most apparent. In so far as vector-borne diseases become associated with

[2] Manual on Environmental Management for Mosquito Control, with special emphasis on malaria vectors, WHO Offset Publication no. 66, World Health Organization, Geneva, 1982.

such developments, they detract from the benefits. Few, if any, studies seem to have attempted to draw up a total balance-sheet, incorporating both the positive and the negative effects of irrigation on health, and perhaps it is time to consider attempting this task.

In the general task of maximising benefits to the people, the medical, engineering and agricultural professions should be encouraged to perceive themselves as working towards very similar objectives. Each needs to understand the constraints that govern the professional activities of the other actors in the irrigation scene. The occasional representation of the engineering and medical aspects of irrigation as somehow mutually antagonistic is unhelpful as well as inaccurate.

The trends we have outlined here, especially the search for improvements in water management and other aspects of irrigation management, offer scope for collaboration between the professions, whose goals seem to require similar strategies.

Within this context, the need for research still exists, and two fields can be defined for this: first, the need for more quantitative analysis and predictive capacity in regard to the health impacts of alternative management and operational options. Management, in a multi-parameter activity like irrigation, often involves compromises between contradictory pressures, and managers require some predictive capacity if they are to make properly-balanced decisions.

Secondly, and for broadly similar reasons, we continue to need better cost/benefit and cost/effectiveness guidance. The changing world food supply situation is putting new stress on the economics of irrigation. Managers facing budgetary difficulties and also designers planning rehabilitations, need to be able to evaluate vector-control options in financial terms.

Any movement towards smaller-scale projects, and towards management devolution to farmers, such as we have discerned above, implies a greater need for preventive public health measures, of which education is probably the most prominent, since in these circumstances there will not always be an active public-sector irrigation agency that can be asked to take on a vector-control role.

All of these fields are eminently suited to the sort of inter-disciplinary studies which PEEM can promote.

FIGURE 1

INDICES OF AGRICULTURAL PRODUCTION

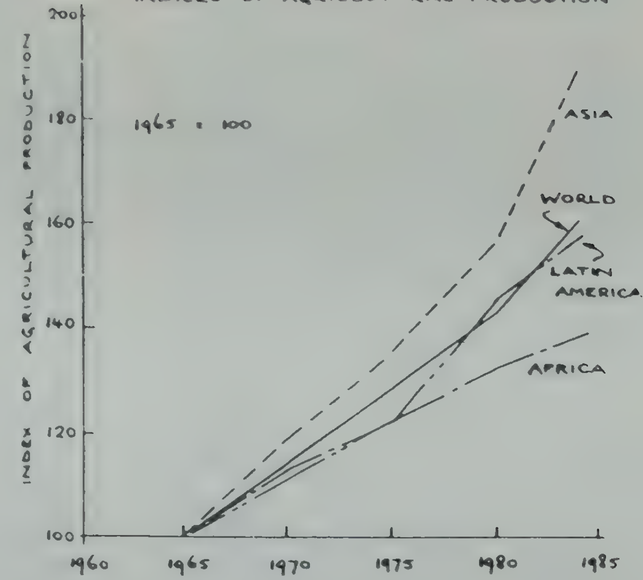


FIGURE 2

INDICES OF AGRICULTURAL PRODUCTION PER PERSON

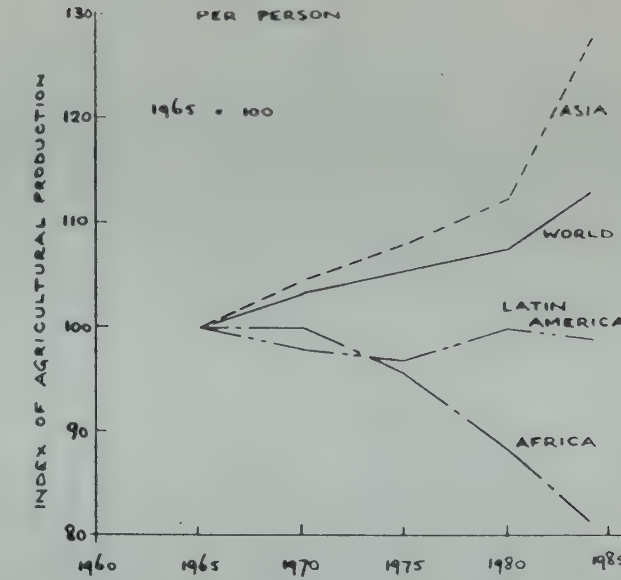


FIGURE 3

EXTENT OF IRRIGATED LAND

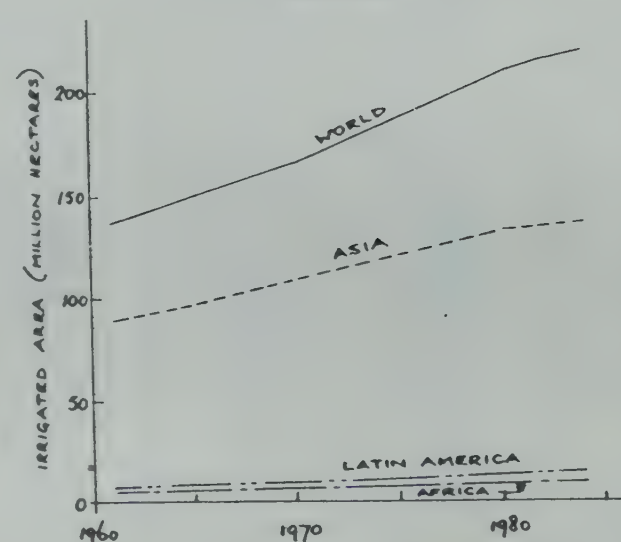
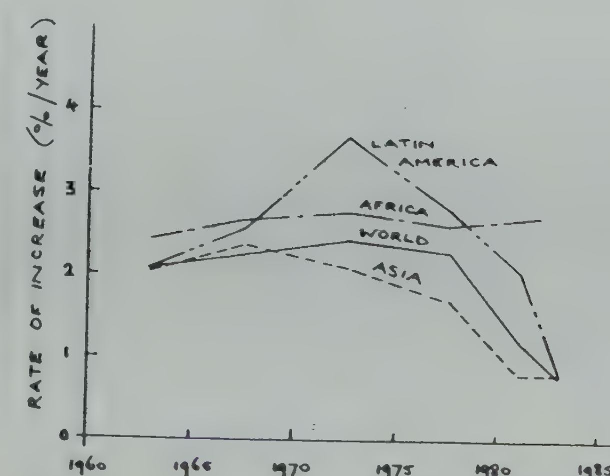


FIGURE 4

RATES OF INCREASE OF IRRIGATED AREA



14. CHANGES IN IRRIGATION TECHNIQUES AS A MEANS TO CONTROL DISEASE VECTOR PRODUCTION

F.P. Amerasinghe[1]

Introduction

Land, food, housing and the prospect of better living standards have been the great benefits of irrigation schemes the world over. Adverse effects on human health, especially by vector-borne diseases such as malaria, schistosomiasis, Japanese encephalitis and the filariases have equally been recognized as one of the great drawbacks of these schemes. Health related problems in irrigation schemes in general, and vector-borne disease problems in particular, have been extensively reviewed over the past decade, some examples being McJunkin (1975), Bradley (1977), Rosenfield and Bower (1979), WHO (1980, 1982), Hunter **et al.** (1982), Cairncross and Feachem (1983), Jewsbury (1984), Mather and That (1984), Service (1984), Goonasekere and Amerasinghe (1987) and Webbe (1987).

Service (1984) points out that the development of irrigation schemes does not necessarily imply increased risks from vector-borne diseases, if proper planning is done to minimize such hazards. To a great extent, the problems are due to a lack of awareness of the potential disease implications of irrigation on the part of the planners and operators of such systems. This article briefly reviews the major types of irrigation systems in operation at present time in relation to vector production, and irrigation techniques that may be useful in disease vector control.

Types of irrigation system

There are three primary types of irrigation systems: surface irrigation, sub-surface irrigation (or subirrigation) and over-surface irrigation.

* Surface irrigation: this system conveys water directly on the soil surface along channels which vary widely in shape, size, and hydraulic characteristics. It can be used on almost all irrigable soils and most crops.

Surface irrigation is the oldest and still the most extensively used method of water delivery in agriculture. It is the system most closely associated with the creation and maintenance of vector-borne disease situations. Basically the problems arise because of the creation of bodies of standing, or flowing water, which are utilized by a variety of insects (e.g., mosquitos, blackflies) and snails, which play a role in the transmission of human disease.

* Sub-surface irrigation: this system provides water to the root zone of crops by raising the natural water table, or by creating one, over relatively large, impermeable soil strata. Subsurface irrigation avoids the creation of above surface standing water, with a consequent saving in water usage by reducing

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surface evaporation, and with obvious implications in relation to the breeding of disease vectors. However, fields suitable for this type of irrigation must have a relatively high natural water table, and/or relatively impermeable soil, as well as a high capacity drainage system that prevents the possibility of sudden or excessive rainfall raising the water table above the crop's normal root zone. These limitations greatly restrict the widespread application of this technique.

* Over-surface irrigation: this is essentially a pipe-borne water delivery system that is often used for topographic and soil conditions (such as hilly terrain, excessively sandy soil or soils with variable water intake rates in contiguous fields) that make surface or subsurface irrigation inefficient or expensive. Two major types are recognized: sprinkler and drip irrigation.

Sprinklers are a versatile means of applying water to the surface of any crop or soil. They can apply water to soils at rates equal to, greater than or less than the soil infiltration rate - a flexibility that has important implications for the control of vector-borne diseases, since it is possible to eliminate accumulations of surfacewater by this technique. Sprinkler systems may be portable, semi-portable or stationary, and their operation can be either manual or automatic (Christiansen and Davis, 1982). A variation of this system is the use of perforated pipes, instead of a spray head, to provide a rain-like application. Water application efficiencies for well designed sprinkler systems are generally in the 70-80% range, but may approach 85% or higher for low wind conditions or night irrigation when temperatures are lower and humidity higher. However, sprinkler irrigation systems have many disadvantages, too, most important of which is the high cost of pumps, pipes, fittings, nozzles, and fuel. Environmental factors such as wind can distort the spray pattern and reduce efficiency.

The drip (or, trickle) irrigation method uses a pipeline system with closely spaced emitters to apply water directly to each plant. There is a near continuous, direct application of water to the soil, resulting in the root zone having a water content between saturation and field capacity. The water application rate is never as great as the infiltration rate. Thus there is no surface run off of water resulting in a high water efficiency and the elimination of potential disease vector breeding sites. Despite these attractions, installation expenditure is high, and the system is basically suited to high value crops that give a sufficient return to offset the investment in installation and maintenance.

There is little doubt that sprinkler and drip systems, and to a more limited extent, subsurface irrigation, provide useful techniques for providing irrigation water without increasing the hazards of vector-borne disease. However, costs of installation and operation of these methods at present greatly limit their usage, particularly in the context of the developing countries of the world where the need for food production and the risks of vector-borne diseases are high, while financial and technically competent manpower resources are scarce. Small wonder, then, that the cost-efficient surface irrigation systems predominate. Changes in techniques of water delivery and drainage in such installed or planned systems offer the most immediate means of effecting the reduction or elimination of vector-borne diseases in these schemes.

Techniques of irrigation water delivery.

Three types of irrigation water delivery are generally recognized: the continuous flow system, the demand system, and the rotation system. Under the first method, each user receives his share of water as a continuous flow. Few control structures are incorporated into the system, which is wasteful of water and contributes to waterlogging of the soil. The demand system involves the delivery of water to fields at times and in quantities requested by the user. It is ideal from the user's viewpoint because it

allows him to irrigate each crop when water is needed and to use a stream size that he finds most economical. This type of system requires a flexible operational organization that can match daily supply with demand. It is not economically feasible to design unlimited capacity in the canal system; thus at peak times the user demand may exceed project capacity and a switch to one or both of the other delivery systems may be required. The rotation system is probably the most flexible of the three. Under this method, water is delivered to each user in sufficient quantity for a fixed period of time, under a prearranged schedule. Rotations in water delivery can be made between two water users, two or more groups of users under a single lateral canal, two or more laterals or between larger divisions of the whole canal system. Under careful management, good irrigation efficiencies can be achieved: studies have shown that up to 50% savings on drainage water can be achieved by this method in rice ecosystems (IRRI, 1975).

The continuous flow system probably represents the worst-case situation in relation to vector-borne diseases, regardless of the type of crop. Water is continuously present in the canals, fields and drainage system during the entire period of irrigation of the crop. Seepage from the delivery and drainage network or, in many cases, the inadequacy of the drainage system coupled with uneven terrain, results in the accumulation of water bodies in areas external to the irrigation network proper. Thus, diverse breeding habitats are available to suit the individual ecologies of the different species of mosquito, blackfly and snail vectors of diseases such as malaria, Japanese encephalitis, onchocerciasis and schistosomiasis that are associated with irrigation schemes, particularly in the tropics (WHO, 1980, 1982, Mather and That, 1984, Jewsbury, 1984). The demand system should theoretically reduce the problem of water accumulation in fallow fields and of excess water overloading the drainage network. However, this will only happen if the farmers themselves exercise discipline in water usage and do not demand an excess of water over actual usage as an insurance against problems of equitability and timing of water distribution that are a common cause of strife in rice irrigation schemes. Rotational systems appear attractive: the periodic and sequential drying and flooding during an irrigation cycle would potentially reduce the availability of vector breeding sites. The rotational system, also referred to as intermittent irrigation, has been the subject of particular interest in relation to vector control.

Intermittent irrigation: This requires a well designed irrigation and drainage network for rapid flooding and drying, a critical factor being that canals and fields must be devoid of all surface water during the drying phase to prevent residual mosquito breeding. The success of water rotations in vector control would depend on the size of units undergoing rotation and the duration of rotation: small units undergoing drying and flooding in succession could still leave sufficient breeding sites in the overall system at any given time for vector maintenance and rapid recolonization of recharged units. Water rotations carried out over large segments of the irrigation system thus offer the best means for effecting significant reductions in vector breeding. The durations of rotational water deliveries and shut-offs must be such that mosquito vectors will be either flushed or dried out before successfully completing immature development - a duration that can be as short as five days for **Similium** spp. (Cairncross and Feachem, 1983). Thus, factors such as soil type and land-shaping that affect surface drainage are important to success in vector control by this technique.

Intermittent irrigation can be applied for vector control only where it is introduced as a measure for water conservation without adversely affecting crop yields, and is therefore acceptable to both farmers and systems operators. There is evidence that when carefully planned and operated the method may actually increase yields, especially in rice culture (Cairncross and Feacham, 1983; Pao-ling Luh, 1984; Self and De Datta, 1987). However, other reports indicate decreased yields, especially under drying periods greater that 5-7 days duration (IRRI, 1974; IIMI, 1986). Thus, a factor that will contribute to the success of this method in both water efficiency and vector control is the development of high yielding rice strains that are tolerant of soil

drying between water applications. Traits leading to drought resistance exist in 8000-9000 strains of rice currently cultivated (Myers, 1984), and rice breeding programmes should attempt to develop these characteristics so that high yields, efficient water usage and low vector production may be simultaneously achieved.

Field trials have shown intermittent irrigation to be effective in both snail and mosquito control. Water supplied on a five day rotation resulted in the complete absence of snails in an irrigated area in Iraq: in the Philippines, intermittent irrigation in an area originally irrigated by ponding resulted in snail reduction of from $200/m^2$ to less than $1/m^2$, while rice yields increased by more than 50% on a ten day rotation regime (Cairncross and Feachem, 1983).

Reductions in larval densities of over 90% in rice field breeding mosquitoes such as **Anopheles atroparvus**, **A. aconitus**, **A. sinensis** and **Culex tritaeniorhynchus** have been achieved in field trials of intermittent irrigation (Hill and Cambournac, 1941; Pao-Ling Luh, 1984). However, in actual practice a delicate balance has to be struck between the water regimes most suited to optimum crop performance and vector control. Another aspect that needs examination is the overall impact of vector density reductions on disease transmission. In China, 80-90% reductions in immature and 50-70% reduction in adult densities of **A. sinensis** and **C. tritaeniorhynchus** have been reported as a result of intermittent irrigation, but the impact of these reductions on malaria and Japanese encephalitis transmission in the areas is unknown. In Japan, studies have shown reductions in both larval and adult population indices of **C. tritaeniorhynchus** in rice fields during periods of intermittent irrigation. However, the fluctuation in the densities of female culicines attracted to pigs (the amplifier host for the Japanese encephalitis virus) could apparently not be related to the water distribution regime or mid-season drainage.

Mogi (1987) concludes that although intermittent irrigation in rice culture has created the possibility of achieving higher yields and mosquito control at the same time, its effectiveness is limited by the fact that rice still requires a high water input. Thus, for optimal control, intermittent irrigation must be practised simultaneously for all rice fields in a large area during the entire cultivation season under conditions favourable to rapid drying.

Water level fluctuation: the fluctuation of water levels and release of sudden water flushes can be effective against various species of **Anopheles** and **Culex** mosquitoes (malaria, encephalitis), the blackflies **Simulium damnosum** and **S. neavei** (onchocerciasis) and various species of **Bulinus** and **Biomphalaria** snails (schistosomiasis). Fluctuations in water level are designed to flush out larvae or change ecological characteristics of breeding places (such as vegetation, aeration and flow rate) to discourage anopheline, culicine and blackfly breeding. The latter, require well aerated, fast flowing or turbulent water, and are thus sensitive to changes in water level and velocity. Water level fluctuations are used to strand snails on the banks of reservoirs and canals, so that they die of desiccation. This is likely to be less successful in earth-lined dams and canals where snails can aestivate in wet or drying mud, or amongst vegetation. In addition to stranding, fluctuations in flow velocities may also discourage snail colonization, which rarely occurs when peripheral flow velocities in streams and canals exceed 30-35 cm/sec (Webbe, 1987). Water level fluctuation has been used successfully in mosquito control: in the Tennessee Valley, USA, for instance, continual water level fluctuations by spillway discharges regulated so as to eliminate the formation of static, shallow water breeding areas, have been successful in controlling the malaria vector **A. quadrimaculatus** (Tennessee Valley Authority, 1947). When several vector-borne diseases are present at the same time, the use of this method can create problems. Cairncross and Feachem (1983) point out that in West Africa, water level fluctuation may be successful against the vectors of schistosomiasis (Bulinus and **Biomphalaria**), and onchocerciasis (S. **damnosum**), but malaria transmission could increase due to A. **gambiae** breeding in transient sunny pools created by fluctuating water levels.

Flushing can be effective in mosquito control beyond the level of the canal system. It is effective in rice fields, provided the fields have multiple sluices arranged so that water currents are induced over the entire surface. However, an excess of irrigation water would be required, and flush water must be drained away completely, or concentrated in small areas where mosquito immatures may be destroyed by chemical or biological agents (Mogi, 1987). Without these safeguards, flushing can cause mosquito outbreaks, particularly if the drainage network is inadequate. Flushing may also have the advantage of being less harmful to natural aquatic predators than intermittent irrigation. Mogi (1987) has observed that while small dytiscid beetles may be flushed out of rice fields together with immatures of **A. sinensis** and **C. tritaeniorhynchus**, predators such as dragonfly and damselfly nymphs that cling to the mud or vegetation, and strong swimmers such as fish, could resist the water current and thus remain in the fields to contribute to natural control.

Water level fluctuations in dams may be useful for snails other than the amphibious **Oncomelania**, as well as for mosquitoes. However, lake margins must be steep and kept free of vegetation, especially where regular fluctuations are not possible. Shorelines must be uniformly graded to prevent pool formation where mosquitoes and snails can breed during drawdown periods. Where rapid changes in water level are possible, shallower shore lines may be acceptable, since the stranding effect will be greater. Field studies in Puerto Rico have shown that spillway drawdowns of 0.5 m/day every 5-20 days during the snail breeding season were sufficient to remove Biomphalaria snails - not by killing them but by preventing reproduction, since adult snails could not lay eggs while stranded, and the few eggs laid were susceptible to drying (Jobin, 1970). Such rates limit the technique to small reservoirs (Cairncross and Feachem, 1983).

Conclusion

After the failure of the insecticidal weapon nearly two decades ago, it has become increasingly clear that there is no single method of control that will work for any or all of the various vectors that transmit human diseases. Techniques reviewed in this article, such as sprinkler, drip and intermittent irrigation, and water level fluctuation, cannot by themselves achieve total success in vector control. However, they have definite potential as components of an integrated approach to disease control when appropriately used. There needs to be a greater impetus to evaluate and refine techniques such as these so that their potential may be translated into actual operational usage. As Cairncross and Feachem (1983) point out: "The area of irrigated land in the world is increasing at over one million ha./year and special measures are required if the benefits of irrigation schemes are not to be outweighed by the damage they do to public health ." The need today is to communicate this sense of urgency to the various administrative, technical and social components of an irrigation system that need to cooperate in developing and implementing an integrated strategy.

15. FOOD FISH AS VECTOR CONTROL, AND STRATEGIES FOR THEIR USE IN AGRICULTURE

T. Petr[1]

Introduction

This paper reviews food fish as one of the important biological control agents of vectors of parasitic diseases. It discusses the use of fish in different situations as related to agricultural practices. The fish considered here are either directly involved in vector control, or the vector control exercises a negative impact on fish. Modifications of the aquatic environment through activities of some fish (e.g., grass carp) are also discussed as such biomanipulation is of direct significance for the aquatic vectors. The dual importance of fish both for human food and for vector control is highlighted and recommendations are put forward on how to optimize their use in the future.

Environmental modifications for agriculture development

1. Deforestation, erosion, sedimentation

Although forest removal is not necessarily always for agricultural expansion purposes, this activity is usually followed by agricultural development on such lands. Deforestation leads to increased erosion and sedimentation, and through such environmental changes it enhances the vector development in certain situations. Increased erosion results in an increase in water turbidity, increased sediment deposits and it affects the insectivorous-larvivorous and molluscivorous fish. Such fish are visually-oriented animals, and a decrease in visibility of prey will reduce their feeding efficiency. Further impacts of siltation on fish are the reduced egg and larval survival, altered breeding behaviour, reduced growth rates, reduced population size and, in extreme cases, interference with respiration (Bruton, 1985, Lynch, **et al.**, 1977). On the other hand, sediments will also have impact on the fish food base and in extreme situations make the habitat unsuitable for insect larval development and for snails.

2. Impoundments

Mosquito problems have been associated with many impoundment projects throughout the world. Typical mosquito-producing habitats associated with impoundments include areas behind the shoreline that become flooded by seepage or wave action. Mosquito production in impoundments is frequently associated with creek, stream, or river inlets (Hayes, 1976). The embayments formed at these inlets often become clogged when the creek channels are not properly cleaned by routine operation and maintenance procedures, and silt with other debris fills the area. Such areas often develop into marshes that become heavily infested with mosquito larvae. Mosquito problems are associated, as well, with siltation within the lake or reservoirs. Intensive and rapid siltation may also destroy some fish spawning areas and lead to reduced fish production. The upper shorelines of many irrigation impoundments develop grass habitats that reduce wave action and protect mosquito larvae from fish and other predators.

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The use of fish for mosquito vector control in large impoundments covered by aquatic weeds and rich in submerged trees, as found in tropical forest and savannah-woodland area reservoirs, is usually ineffective, and chemical or environmental (engineering manipulation) measures are usually applied. Biomanipulative measures using the herbivorous fish grass carp to reduce the amount of submerged vegetation have been tried on the Gatun Lake in Panama, but were not found to be cost-effective. Controlling weeds is frequently pursued in such large reservoirs for navigation purposes rather than for vector control.

3. Irrigation systems

Malaria and schistosomiasis are the two major diseases which spread through water associated vectors in irrigation systems. Due environmental considerations should be given to the usual three sections of an irrigation complex: the water storage, the system of distribution canals and drains, and the irrigated cropland. Another aquatic habitat, resulting from poor irrigation practices, is formed by water bodies resulting from seepage. Excess irrigation water, not properly removed, is ideally suited for the growth of many species of mosquitos. The obstruction effect of aquatic weeds, resulting in slowed down water current and in increased siltation rates enhances the establishment of mosquito larvae and snails.

Until recently, **Gambusia affinis** was the most recommended and commonly used larvivorous fish for controlling mosquito vectors in irrigation systems. Information gathered (Informal Consultation, 1981) showed that **Gambusia**, **Tilapia** and **Poecilia** spp., in that order, were used most commonly for larval control mainly against **Anopheles** spp. and to some extent against **Culex** spp and **Aedes** spp. A review of ongoing research has indicated the need for a more coordinated effort to obtain an accelerated progress in the utilization of fish. The Informal Consultation recommended that effort be made to identify new indigenous species which should receive priority over the exotic fishes in future work. A guide for preliminary identification of some larvivorous fish focusing on small, common species of tropical and subtropical areas of Africa and Asia was prepared by Haas (1984), which included advice on the selection of types of fish that should function well as larvivores, their collection, transporation and propagation.

A study of irrigation canals in Gezira (Sudan) identified as the major problem facing the system the proliferation of aquatic weeds and the water associated vectors of diseases: snails serving as intermediate hosts of **Schistosoma** parasites and mosquitos transmitting malaria (Coates, 1984). Coates found that the juveniles of the tilapia **Oreochromis niloticus** had consumed far more mosquito larvae than **Gambusia affinis**, introduced some time ago for mosquito control, but not managed. Coates considered **Gambusia** to be of little value due to its low density and patchy distribution and suggested the need for its management in terms of both distribution and density, if the fish were to be efficient in controlling mosquitos. This confirmed the opinion expressed by Davidson (1982) that mere presence of larvivorous fish in an area does not necessarily ensure a reduction in the mosquito population of that area.

Irrigation canals of Gezira were found to contain a relatively high fish biomass ranging between less than 50 kg/ha to 2786 kg/ha, with a mean value of 660 kg/ha, indicating considerable potential for the use of irrigation canals for fish production. Problems still exist with accumulation of pesticide and herbicide residues in fish in the Gezira canal system, which could however be resolved by switching to non-residual chemicals.

Attempts to control aquatic weeds in irrigation systems have involved the use of herbicides, or the mechanical or manual removal of the plants. Biological control of aquatic weeds using food fish in irrigation systems has been successfully attempted by using the exotic grass carp (**Ctenopharyngodon idella**). In Africa, and also elsewhere in the tropical and subtropical countries, no other fish has been discovered which could compete with the efficiency of this species. In Egypt, reduction of the snail population

was suspected to be the result of the feeding of grass carp on leaves of macrophytes on which egg masses are deposited. In Madagascar, Vincke (pers.comm) observed **Tilapia zillii** and **Oreochromis niloticus** directly feeding on snail eggs deposited on the surface-floating leaves of **Nymphae**. Van Schayck (1986) suggested that increased predation by the endemic fish **Tilapia zillii**, **Clarias lazera** and **Haplochromis** spp. in biologically manipulated canals may further assist in reducing the snail density. In Volta Lake in Ghana omnivorous fish consumed considerably more snails when the aquatic vegetation was removed (Paperna, 1969).

4. Rice fields

Much of the irrigation water throughout the tropical and subtropical world is being used for rice culture. The use of **Gambusia affinis** in rice fields has been criticised among others by Farley and Younce (1977) who considered it a rather poor controlling agent as it preys to a large extent on non-target organisms, such as crustaceans and chironomids, switching to feeding on mosquito larvae only when other food sources are in short supply. Also, the fish appeared to prefer the deeper open portions of the water in the rice fields, while mosquito larvae were most abundant in the shallow protected areas of the field. Thus, the predator and prey were isolated from each other ecologically (Reed and Bryant, 1972). Experience in the efficiency of larvivorous exotic fish has been varied, and Mather and Trinh (1984) expressed the opinion that there is little real evidence that introducing fish into habitats already colonized by a rich fauna of natural predators, has really led to any worthwhile reduction in disease transmission. Indigenous larvivorous fish have been found to be highly effective in mosquito control and such fish are well adapted to local conditions and readily available for mass rearing and dissemination.

Food fish have been used for control of vectors especially throughout Asia. In Southeast Asia, virtually everywhere that irrigated rice is grown, fish are captured in flooded fields and a wide range of species is either cultivated or captured. Ruddle (1982) has reviewed the rice-associated food-fish species. In China, raising grass carp and other fish in paddy fields led to an 80 to 90 per cent reduction in the density of mosquitos and their larvae in rice-growing areas in Henan Province (Anon., 1984). Grass carp averaged about 400 mosquito larvae per day. The exotic tilapia **Oreochromis niloticus**, now widely used in tropical South-East Asia, is also an efficient larvivore. In the Philippines, with supplemental feeding, combined **O. niloticus** and common carp culture in rice fields has given a fish yield of 692 kg/ha/year. Both fish are larvivores.

The principal constraints to rice field fisheries and to the use of fish for vector control in rice fields are the toxicity of agricultural chemicals and a regular water supply. In some areas of Brazil, pesticide use and mechanical cultivation in larger fish farms make the possibility of combined rice and fish cultivation unlikely in the future (Mather and Trinh, 1984). The persistence of pesticides in rice fields may be a long-term constraint on fish cultivation. This can be resolved by using insect-resistant rice varieties and pesticides of low toxicity to non-target organisms. With carbofuran, it is now possible to protect the rice crop from pest and disease infestations with no danger of fish mortalities or residues being left in the fish tissue.

5. Fish ponds

In some parts of the world, fish ponds may provide the only free surface water available to mosquitos under dry season conditions. For example, **Anopheles funestus** prefers grass, reed or floating vegetation, grass-grown shores of ponds and dams and some other habitats. Protection of pond embankments by grass planting leads to the encroachment of grass into water - an ideal environment for **A. funestus**. Fish cannot reach the larvae which are sheltering in a dense tangle of grass stalks. If a pond is

reasonably deep and is well stocked with fish it will be unsuitable for **Anopheles gambiae**, which prefers shallow, small water bodies fully exposed to the warmth of the sun.

In Africa fish farming is also a significant factor in the spread of schistosomiasis. Snail control in fish ponds may demand the constant attention of local fisheries and health workers. The normal use of pond drying and aquatic weed control techniques, combined with occasional use of molluscicides, may be impractical where funds are limited and fish pond workers are recruited from an unskilled labour force.

Larvivorous fish and snail-controlling fish have been successfully used in fish ponds and dams in Zaire, Cameroon and Kenya. New fisheries schemes include in their fish production programmes provisions for fish control of snails. Reproduction trials, efficiency evaluation of molluscivorous fish in mono- and polyculture, stocking of vector/host controlling fish and monitoring of the results are being included in the World Bank/FAO aquaculture projects for Africa (Schmidt and Vincke, 1981, Vincke, 1985). The subject is also included in aquaculture training courses organized by FAO. Snail-feeding fish in Africa are well known, with the two most efficient fish being **Astatoreochromis alluaudi** and **Haplochromis mellandi** (Schmidt and Vincke, 1981). In Zambia, **H. mellandi** was included into the polyculture stocking programme for fish production on the Shishamba fish farm (UNDP/FAO/1980) and its stock is being maintained.

Indigenous fish species of both food and vector/host control significance are also available for a number of countries of Asia. In India, a number of species of **Puntius** are known to be larvivorous, as well as **Etroplus suratensis**, **E. maculatus** and **Channa striatus**. Environmental constraints are placed on the use of **Puntius** by pollution as the fish prefers clean waters. **Channa**, as well as the widely used **Oreochromis niloticus**, are larvivorous only in their young stages, and the use of **Channa** is limited due to its predatory habits (Babu Rao and Yazdani, 1977, Menon and Rajagopalan, 1977). Other larger larvivorous food fishes include **Cyprinus carpio**, **Carassius auratus**, **Anabastestudineus**, **Trichogaster** spp., **Helostoma temminckii**, **Osphronemus goramy** (Haas, 1984). **Kuhlia taeniurus**, a fish mostly used as bait for fishing, and widely distributed along the coasts of East Africa, Indonesia, the Pacific Islands, northern Australia and around the islands of the Indian Ocean, is a most commonly used larvivorous fish in the Maldives (Velimirovic and Clarke, 1975) where in spite of being a sea fish, it adapted itself to life in wells which are the only source of drinking water supply. The small fish **Gambusia affinis**, widespread in Africa, is known to be eaten in large numbers in Madagascar (Vincke, pers.comm).

Among organisms considered for biological control of the host snails have been several crustaceans: the freshwater crab **Potamon**, the freshwater crayfish **Astacus** and **Cambarus**, and the giant prawn **Macrobrachium rosenbergii** have been tested in experimental work and found useful. A polyculture of **M. rosenbergii** and **Tilapia aurea** has been suggested as having a high potential both for biological control and production. This would fulfill the requirements of fish farmers located in tropical countries with schistosomiasis problems and pressing needs to develop animal protein sources (Lee **et al.**, 1982).

Biological control of aquatic plants can be very effective in reducing populations of mosquitos that favour such vegetation, but at the same time changing the habitat in this way may result in colonization by species that can tolerate or actually prefer waters without plants. Some tilapias, common carp, tawes (**Puntius**) are herbivorous fish which through their suppression of aquatic vegetation have facilitated reduction in vectors of malaria. Grass carp has been used for biomanipulation of selected water bodies such as Lake Kinneret, irrigation canals in Egypt and numerous fish ponds overgrown with aquatic weeds. Grass carp, with its multiple function, (i.e., for aquatic plant control, vector control, modification of the environment through removal of plants, enhancing the polyculture with plankton feeding fish), is a unique biological control agent as well as a valuable food fish.

6. Rivers

The release of underpopulated lands for expansion of agriculture is among the priority objectives of two large vector control programmes in Africa: the Onchocerciasis Control Programme (OCP) with its target organisms being black flies (Simulium) of West Africa and tsetse fly control for reducing trypanosomiasis, predominantly in the savanna belts of Africa. Both programmes are closely monitored by fishery specialists as the vector control in both cases involves the use of large quantities of pesticides.

Since 1975, hydrobiological teams have been monitoring the long-term effect of the larvicide on the fish populations in the rivers in the OCP treated areas. There is a wide safety margin between the effective concentrations of the organophosphorus compound temephos for **Simulium** larvae control and concentrations which are toxic to fish. The short term effects on fish in the river Oti in Ghana showed that there were virtually no fish killed (Abban and Samman, 1980). Long-term impact studies on four commercial fish species **Oreochromis niloticus**, **O. galilaeus**, **Alestes nurse** and **Schilbe mystus** from two treated rivers, the White and the Red Volta, which were treated weekly for several years, found no inhibitory effect on the head acetylcholinesterase activity which could be attributed to the treatment of the rivers with temephos (Antwi, 1987). It appears that during larviciding, most of the fish in the treated rivers avoid the impact of the larvicide by swimming downstream. Experiments have shown that river waters beyond 3.0km downstream of the treatment provide a safe place for the fish during temephos application. Temephos is non-persistent in the aquatic environment.

After resistance to temephos developed in some blackfly larvae, a second larvicide, chlorphoxim, was added, and when resistance to chlorphoxim was also reported, the programme added a biological control agent, **Bacillus thuringiensis** serotype H-14. Chlorphoxim is more toxic than temephos to non-target organisms. However, the regular monitoring of aquatic invertebrates and vertebrates in individual countries has shown that no significant irreversible pressure was being placed on any such organisms, and the ecological effects of the vector control operations have been found insignificant.

For many decades the practical approach to exterminating tsetse flies was bush clearing with the objective of destroying vegetation that provides the microhabitat for breeding and resting of the adult fly. This clearing of shade trees from along the river embankments and lake shores has led to soil erosion. Later on, the use of insecticides led to the kill of non-target organisms, including aquatic insects, and in some situations fish as well (Gilmore, 1979). In the Okavango Delta, Botswana, spraying with endosulfan caused some fish mortality and affected the behaviour of survivors. For example, nesting success of **Tilapia rendalli** was reduced by 75 per cent (Matthiessen and Logan, 1984). Introduction of a new type of tsetse fly trap using tsetse attractants and impregnated with insecticide (Allsopp, Hall and Jones, 1985) is a dramatic improvement over other methods used, and environmentally fully acceptable if handled properly, as they do not have the ecological side effects associated with continuous and widespread chemical spraying. However, in an EEC funded massive programme of eradication of tsetse flies in Malawi, Mozambique, Zambia and Zimbabwe, aerial spraying using endosulfan will also be applied. As in at least two countries fish constitute a high percentage of all animal protein consumed (55% in Malawi, and 28% in Zambia) utmost caution is required to protect the food fish and the aquatic environment as a whole from excessive damage.

Cost/effectiveness of vector control

The cost of developing new insecticides and molluscicides is so high that it is becoming prohibitive to introduce regularly new chemicals of this type into general use. Biological control of vectors is of considerable economic value, where an efficient controlling organism has been identified and tested. Coates (1984) considers

the use of fish for biological control agents as financially advantageous to the use of chemical, mechanical and engineering methods and procedures. While the cost/effectiveness of the use of small larvivorous fish such as **Gambusia** is easy to evaluate, especially in small water bodies, it is less easy with many species of the larger food fish where vectors and hosts of parasites comprise only part of their diet, and where, moreover, frequently they consume this type of food only in a certain stage of their life history. A detailed cost/effectiveness evaluation of food fish as vector/host control agents, as compared with other control methods is needed. Such evaluation should include various types of environments, simple and complex situations, and integrated control approaches.

16. EFFECTS OF CHANGING AGRICULTURAL PRACTICES ON THE TRANSMISSION OF JAPANESE ENCEPHALITIS IN JAPAN

Motoyoshi Mogi[1]

Introduction

Japanese encephalitis (JE) was registered in Japan as a notifiable disease in 1946. Despite some variation in the quality of the data collected since that year, the statistics can be considered a sound basis to understand the general trend of JE epidemics over 4 decades (fig. 1). Morbidity rates remained high (1-10 cases per 100,000) for ca. 20 years starting in 1948, but began to decrease rapidly towards the late 1960s. Having reached a minimum in 1976 and 1977 (0.001-0.01 cases), the rate kept slightly higher, but still low (0.01-0.1 cases), since the late 1970s.

Although vector (**Culex tritaeniorhynchus**) control operations or vaccination of pig amplifying hosts were practised very locally and for short periods of time, the country-wide and by now well-established anti-JE operation is based on human vaccination only. Beginning in 1954, vaccine production expanded rapidly around 1965. The effectiveness of vaccination is apparent from the very large decrease in JE morbidity rates among groups of children, the majority of whom are vaccinated (Ishii 1986). However, vaccination alone can not explain the entire decrease in JE epidemics since the late 60s, since morbidity rates decreased markedly also for the elderly with very low vaccination rates. This paper examines the effects of changing agricultural practices and human life style on the intensity and frequency of JE epidemics.

Data and methods

Many of the changes in agricultural practices and human life style have been considered important factors, responsible, to a greater or lesser extent, for a decrease in JE incidence around 1970. Such views appear often based on experiences and impressions in localities and research fields with which a particular investigator is most familiar. To elucidate the factors which have caused a country-wide decrease in JE incidence, environmental changes are to be examined on a national basis without any biasses. However, Hokkaido may be excluded, since no human JE cases have been reported from this northernmost island of the 4 major islands. All the statistics presented in this working paper were taken from Government publications.

Factors affecting vector abundance

* Facts

There is no evidence for marked and country-wide changes in vector abundance for the period prior to the late 1960s. Vector density began to decrease rather abruptly

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towards the late 1960s and stayed at low levels during the early 1970s. Reduction rates were usually more than 90%, reaching 99% in some localities. The vector density began to resurge towards the late 1970s, and has reached levels which may be as high as previous ones. This may be best documented by Watanabe and Kamimura (1983).

* Rice cultivation practices

Surface area planted with paddy rice

The total planted area has decreased as from 1970, following rice production control (fig. 2). This phenomenon can not be cited as a major cause of the vector reduction around 1970, since (1) the reduction rate of planted area in the early 1970s was at the most 18%; (2) the vector density increased towards the late 1970s when the area under cultivation further decreased; and (3) the area under cultivation was at its maximum in 1968 and 1969 when vector density decrease had already begun in many localities.

Transplanting time

The transplanting time has advanced gradually over 30 years (fig. 3) without showing any significant correlation with changes in vector abundance.

Intermittent irrigation

The application of this technique was rapidly spreading during the late 1950s, and it had become common in the early 1960s. No marked change in vector abundance followed this change in agricultural practice with a theoretically high potential for mosquito control (Mogi 1987).

Application of agro-chemicals

(1) Insecticides. There are no indications for vector density decrease immediately following the introduction of synthesized organic insecticides for use in agriculture in the early 1950s. Application intensity increased rapidly in the middle 1960s, and stayed at nearly the same level for ca. 10 years (fig. 4A). This increase preceded vector decrease by 2-3 years, but this discrepancy may be explained considering the possible interaction of multiple factors. Increased intensity of insecticide application could have had an impact on vector decrease. However, it should be noted that more recent (the late 1970s) increases in application have coincided with vector increase. Intensive application of insecticides for agricultural purposes does not automatically cause a reduction in vector densities. Increased application in the late 1960s coincided with a drastic change in component insecticides (fig. 4B). HCH was replaced by organophosphorous (OP) and carbamate (CA) products. The vector larvae had developed resistance to HCH in the late 1960s, but were still susceptible to OP and CA (Buei and Ito 1974). Also CAs are safer for spiders (predators of adult mosquitoes) than HCH. Recent increases in treatment intensity were not accompanied by such changes. Instead, fairly high resistance of the vector larvae to OP and CA was reported (Kamimura and Maruyama, 1983). Follow-up studies proved country-wide prevalence of the resistance (Yasutomi and Takahashi, 1985) and appearance of resistant individuals around 1978 (Takahashi and Yasutomi 1987). Thus, taking susceptibility of the vector larvae to prevailing insecticides into consideration, this offers a plausible explanation of the changes in vector abundance. About the effectiveness of insecticides on the adult females, and whether a similar relationship exists, less is known.

(2) Fungicides Application intensity of fungicides has increased steadily from the 1950s but most rapidly around 1965 (fig. 5A). During this rapid increase, vector abundance remained unchanged. Organic mercury (OM) was replaced by OP and antibiotics since 1968 (fig. 5B). This replacement coincided with the start of vector density decrease. OM is highly toxic to fish, and, in view of its toxicity to

freshwater Crustaceae, probably to aquatic arthropod predators and the vector larvae. OP and antibiotics are less toxic or virtually safe to fish and arthropods including the vector larvae. The total effect of fungicide replacement is difficult to assess.

(3) Herbicides Statistics on the intensity of herbicide applications were unavailable, however, the amount shipped for domestic use would be a rough indicator. This correlation was confirmed for insecticides and fungicides. The shipped amount increased rapidly during the 1960s without relevant changes in vector abundance (fig. 6A). The change in component chemicals could have related more to vector density decrease. PCP, which is fairly toxic to fish and ineffective to the vector larvae (Moriya **et al.**, 1969, Shim and Self 1973), was replaced around 1970 by diphenyl ethers, carbamates and others (Fig 6B). These are relatively safe to fish, and at least nitrofen, chlornitrofen and chlormethoxynil, all diphenyl ethers, could have been lethal to the vector larvae at standard dosages (Maeda **et al.**, 1976). Intensive use of these herbicides may have related to vector decrease around 1970. The vector susceptibility at present is unknown.

(4) Aerial treatment of insecticides and fungicides Aerial treatment techniques spread rapidly during the 1960s, preceding vector decrease (fig. 7). However, the vector resurged towards the late 1970s under the maximum intensity of aerial treatment. Aerial treatment itself is not a major factor determining vector abundance. The cumulative area under aerial treatment is presently ca. 50% of planted area, and of course the net area treated is much less.

(5) Fertilizers. Use of natural fertilizers has decreased and use of chemical fertilizers has increased, both gradually since the late 50s (fig. 8). The relatively rapid decrease in natural fertilizers during the decade from the late 1960s coincided with vector decrease. This parallelism may be superficial, since the vector resurged towards the late 1970s under the minimum application of natural fertilizers.

* Livestock breeding

Number of animal sheds and animals

The cumulative number of farmers keeping cattle, horses, sheep, goats, and pigs was taken as an index of the number of animal sheds. Their number increased gradually since 1945 but began to decrease after the late 1950s (fig. 9). On the other hand, the total number of animals has increased steadily over 40 years following the increase in average numbers of animals kept by each farmer. Large animal sheds tend to be located farther from rice fields and human houses. Thus, blood source animals have increased in number, but, since the 1960s, have become more biased in spatial distribution. Vector abundance, however, did not change following these changes. Recent vector resurgence indicates that blood sources are just as available now as they were before.

Light traps

Use of light traps (LT) for animal care was common for several years in the late 1960s, but this practice was abandoned in the 1970s since farmers realized that LTs catch fed mosquitoes rather than unfed ones. This method is considered to have a high potential for vector and JE control, especially in the current situation of a decreasing number of animal sheds. Despite this potential, there are no indications that vector abundance was seriously affected by prevalence and subsequent abandonment of LTs. This is understandable, since LT setting rates were at most 20% even if all the LTs sold in the late 1960s operated singly at different animal sheds.

Conclusion to this section

Country-wide reductions in vector densities around 1970 and the vector's resurgence about 10 years later are best explained in connection with the application of

insecticides to rice. Not merely application intensity, but the vector susceptibility to prevailing insecticides is of primary importance. Toxicity to natural predators may also have been involved. Herbicides and fungicides may have affected vector abundance through toxicity to the vector or toxicity to predators, but these aspects have been insufficienctly studied.

There is no indication that vector abundance has been seriously affected by considerable changes in distribution and abundance of blood source livestock.

Factors affecting the infectivity rate of the vector

* Facts

Infectivity rates fluctuated but did not show any historical tendency from 1963 to 1972 in Fukuoka (Yamamoto, 1981) and from 1967 to 1984 in Osaka (Nakamura **et al.**, 1985), while in Kyoto the yearly maximum rate was 2% or more in the middle 1960s but usually 1% or less in the early 1970s (Maeda **et al.**, 1978). Infectivity rates of biting populations of the vector are affected by seasonal prevalence of the vector in relation to the pig epizootic cycle, and thus often do not provide very valuable information. Therefore, factors capable of affecting the probability of the vector to become infective are examined in relation to JE morbidity rates.

* Pigsty and pig rates

The number of pigsties increased gradually until the mid 1960s, and has stayed nearly constant since then with recently a slight decrease. Numbers of pigs have increased steadily, but most rapidly during the decade before the mid 1960s. JE morbidity rates did not increase following the early increases in pigsties and pigs, and its incidence began to decline from the late 1960s with high rates of pigsties and pigs.

* Infection rates of pigs

The vector becomes infective by taking blood from viremic pigs. Random serological surveys to predict JE epidemics started in 1965 in all the prefectures, collecting the blood from pigs at slaughter houses. According to prefectural reports from South West Japan where JE epidemics have been most severe, almost all the susceptible pigs were infected with JE virus during each summer except for low epizootic years during the 1970s when pig infection rates often stayed below 50%. These low epizootics in the 1970s coincided with low JE morbidity rates in man. However, the recent resurgence of pig epizootics is inconsistent with the low JE incidence in humans.

* Survival rates of vector females

Prevalence and subsequent abandonment of light traps (see above) did not cause any significant changes in JE morbidity rates. In Korea, parous rates of the biting population decreased after experimental aerial ultra-low-volume application with OP insecticides (Self **et al.**, 1973). This aspect needs to be further studied in relation to agricultural chemicals.

Conclusion to this section

By decreasing the probability of the vector becoming infective, low pig epizootics probably contributed to low JE morbidity rates in the 1970s. However, low JE morbidity rates in the 1980s under resurgence of pig epizootics require additional factors to be considered.

Factors affecting the probability of man-vector contact

* Facts

Quantitative data on the historical change in the probability of man-vector contact are not available.

* Farmer population

Farmhouse residents have decreased gradually over 40 years from nearly 50% to less than 20% of the population, without relevant changes in JE morbidity rates. Most of previous farmers still reside in rural areas, thus, in view of a wide flight range of the vector, the absolute number of people free from the vector does not appear to have markedly increased.

* Labour hours

Labour hours have decreased gradually over 30 years by mechanization in agriculture without relevant changes in JE morbidity rates.

* Housing improvements

Use of electric room coolers has rapidly spread since the late 1970s when resurgence of the vector and pig epizootics began. In 1985, 52% of houses had coolers. Excluding the north (Hokkaido and Tohoku District of Honshu) where the rate remained 10%, the rate is even higher and exceeds 70% in some Districts.

Conclusion to this section

Previously people spent evenings outdoors or in open houses during hot and humid summers. It has become more popular now to spend evenings in air-conditioned, closed rooms with colour TVs and other recreation facilities. This life style became feasible for farmers because of a decrease in labour-hours, resulting from farm mechanization. Many of the houses without coolers are protected from mosquitoes by screened windows. These changes in housing and life style may be a factor preventing resurgence of JE epidemics despite high levels of vector abundance and pig epizootics in the 1980s.

General conclusion

The reduction in vector density in the late 1960s probably resulted from intensive treatment of rice with organophosphorous and carbamate insecticides. This initial reduction could have led to a decrease in JE epidemics simply through the proportionally decreasing number of bites since pig epizootics still remained high. Further reductions in vector densities lowered infection rates of pigs, and therefore could have decreased the probability of man being infected through synergistic effects of (1) lower numbers of bites and (2) lower rates of infective bites. Vaccination further decreased morbidity rates in children. The vector larvae acquired an extremely high resistance to organophosphorous and carbamate insecticides towards the late 1970s, which resulted in the resurgence of the vector and pig epizootics. However, human JE epidemics have stayed low perhaps due to the decreasing probability of man-vector contacts through housing improvements which made rapid progress since the late 1970s. Of course this simplified scheme does not exclude the involvement of other factors for which there is not enough information and evidence.

There are no clear indications relating the marked change in JE epidemic intensity to changes in numbers of pigsties and pigs. This may be an illustration of the difficulty of JE control by introducing barrier animals. Conditions required for barrier animals to be effective could be suggested by model simulation.

The decrease in JE epidemics in Japan since the late 1960s thus resulted probably from unintended effects of environmental changes aside from vaccination. There may be other examples where vector-borne diseases decreased without continuous effective control operations. Overlooked or undescribed factors may have also worked under "successful" control operations. An important element of integrated vector-borne disease control may be to incorporate such factors intentionally into local development programmes.

Post-script by Dr Mogi after editing of this paper for the Technical Discussion:

"Recently I noticed another factor which I had not been aware of before and which might favour the resurgence of **C. tritaeniorhynchus** in Japan. That is the modernized irrigation system. Formerly irrigation water was led to rice fields directly from canals. Therefore fish were distributed to the rice fields together with water. In the modernized system, water pumped up from the canal is distributed to rice fields through underground pipes. When pumped up, large objects such as fish (excluding the smallest ones) are removed. Therefore, in the area with the modernized irrigation system, rice fields are often fish-free".

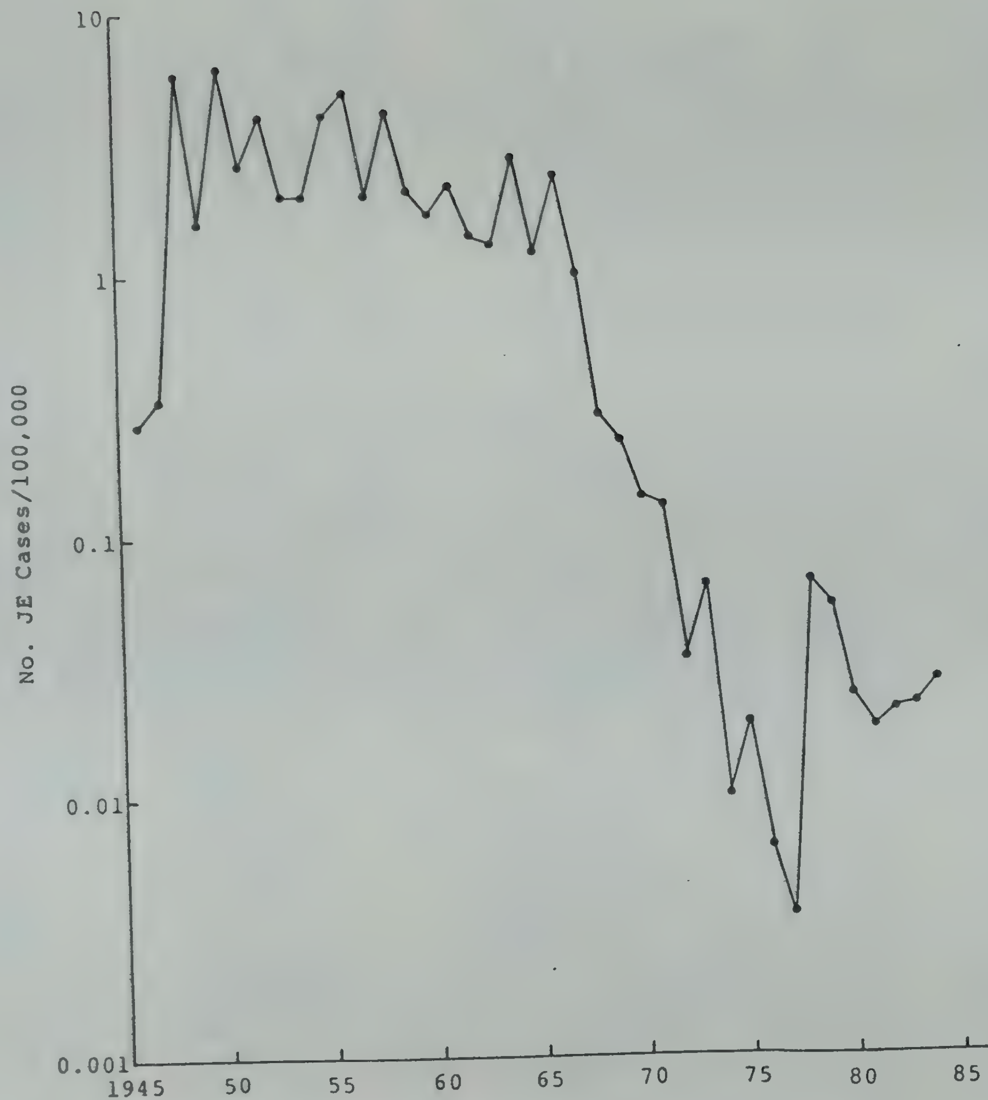

Fig. 1. Yearly change in morbidity rates of JE.

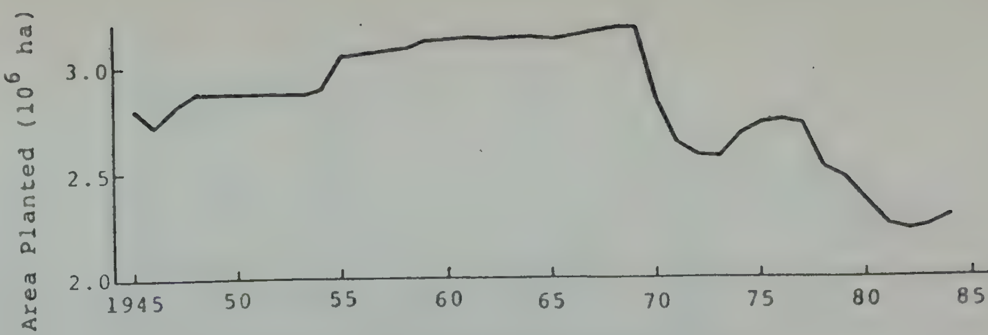

Fig. 2. Total area planted to paddy rice.

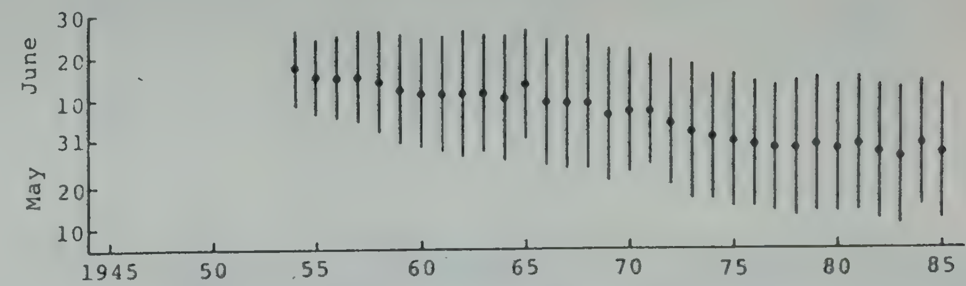

Fig. 3. Mid transplanting time. Mean and S.D. were calculated from mid transplanting time in each prefecture except Okinawa where rice is cropped twice a year.

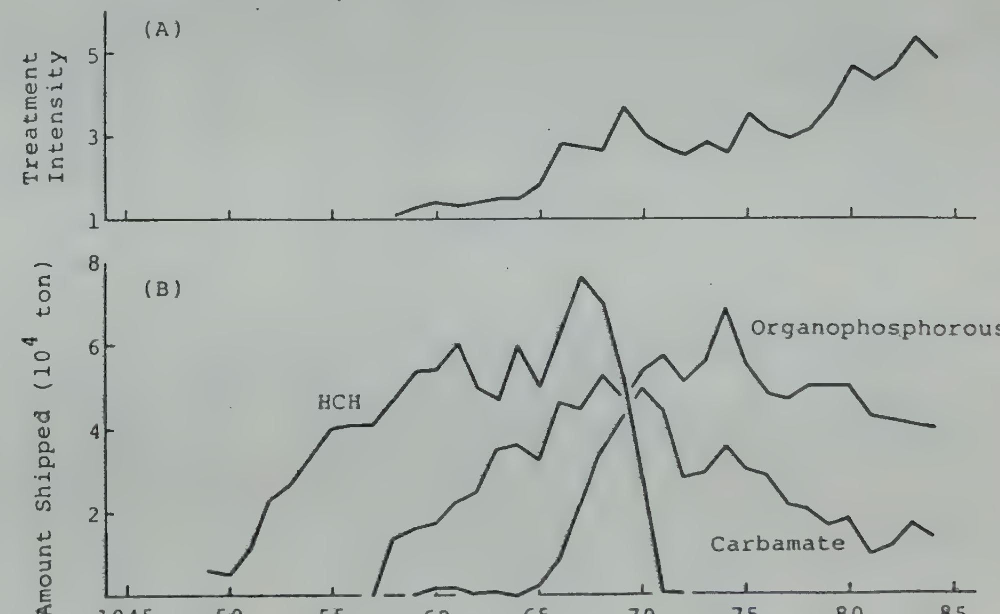

Fig. 4. Treatment intensity of insecticides to paddy rice (cumulative area treated/area planted) (A) and the amount of main insecticides shipped for domestic use (B). Organophosphorous insecticides include diazinon, disulfoton, EPN, fenitrothion, fenthion, malathion, and trichlorfon. Carbamate insecticides include carbaryl, propoxur, BPMC, CPMC, MPMC, and MTMC.

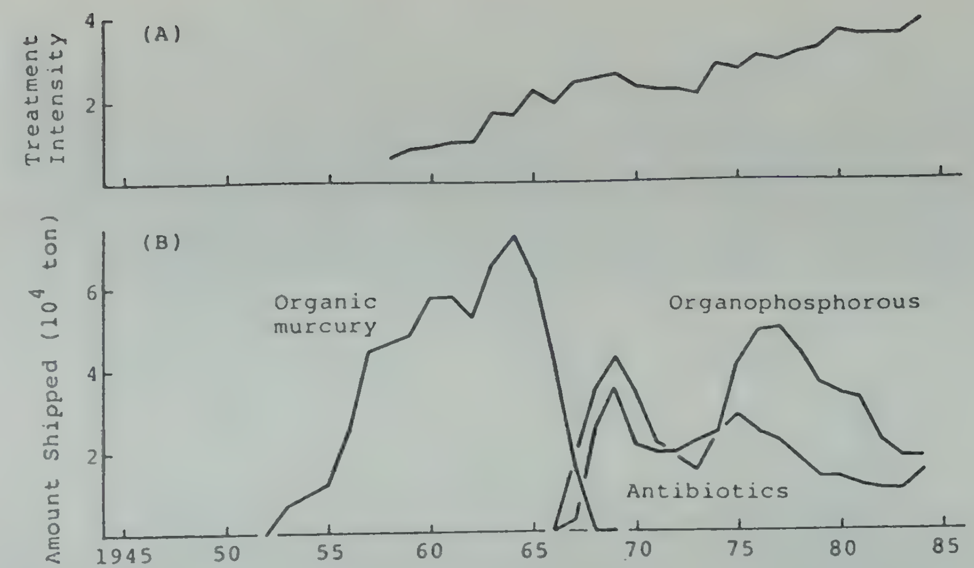

Fig. 5. Treatment intensity of fungicides to paddy rice (A) and the amount of main fungicides shipped for domestic use. Organophosphorous fungicides include edifenphos and IBP. Antibiotics include blastocidin S, Kasugamycin, polyoxins, and validamycin A.

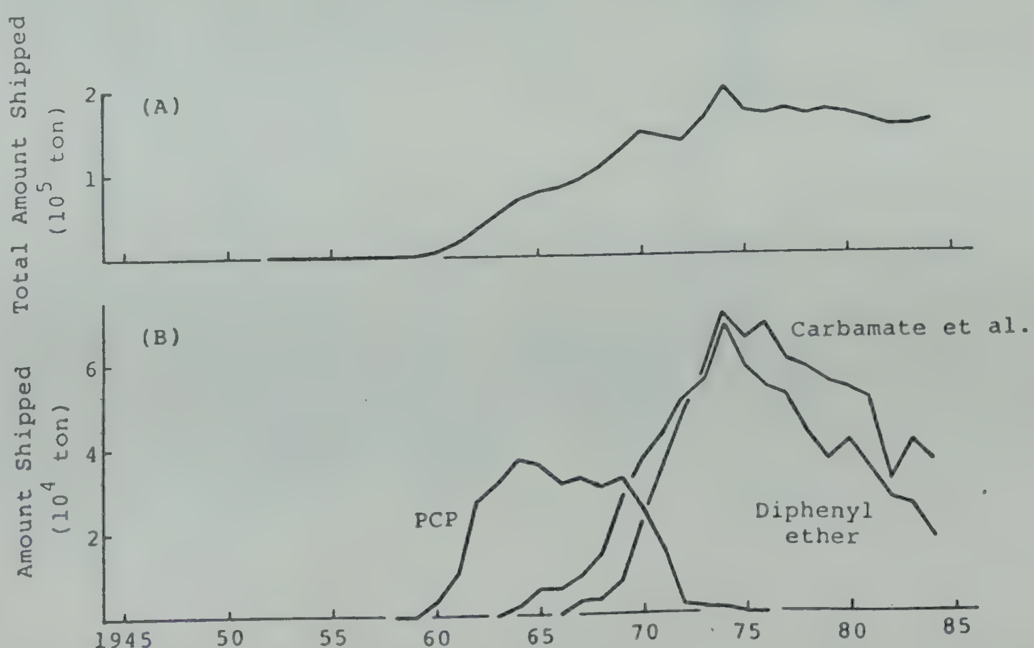

Fig. 6. Amount of total (A) and main (B) herbicides shipped for domestic use. Diphenyl ether herbicides include chlormethoxynil, chlornitrofen, and nitrofen. Carbamate and other herbicides include molinate, swep, thiobencarb, simetryn, MCPA, and MCPB.

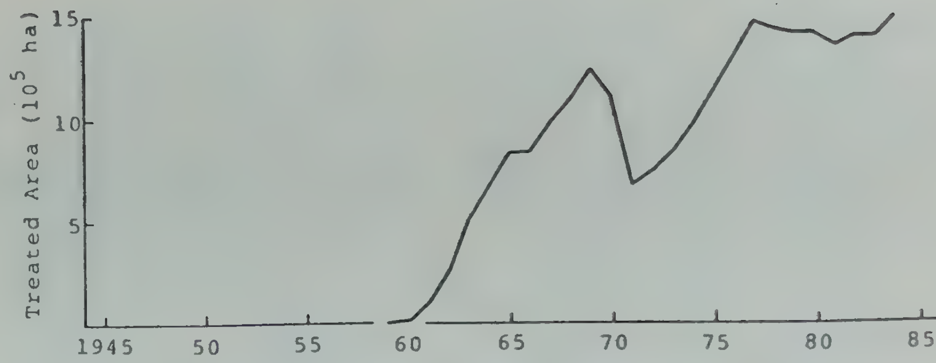

Fig. 7. Cumulative area of paddy rice fields treated with insecticides and fungicides by airplanes.

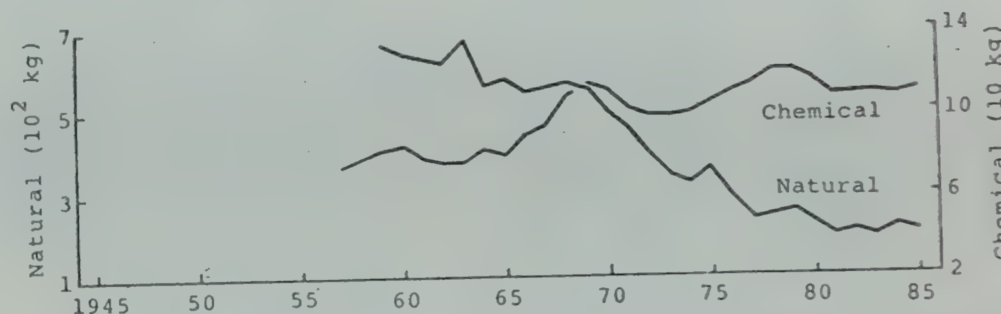

Fig. 8. Amounts of main natural and chemical fertilizers treated per 10 a of rice fields. Natural fertilizers include straws and composts. Chemical fertilizers include ammonium surfate, nitrolime, calcium superphosphate, phosphorite, potasium chloride, and calcium silicate.

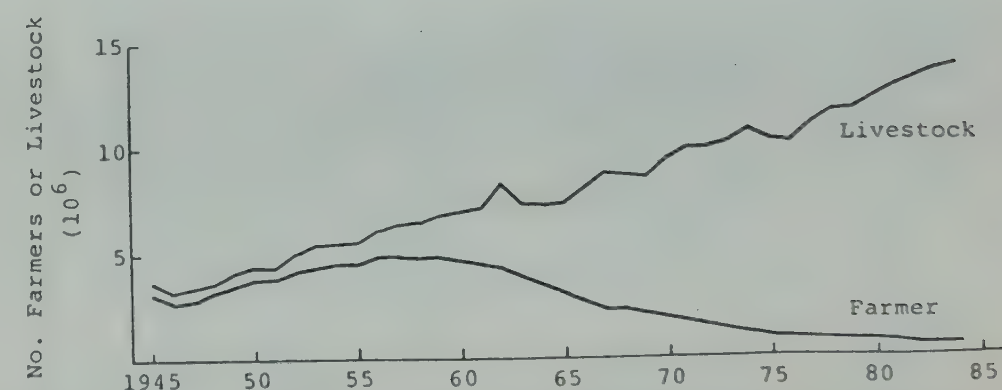

Fig. 9. Cumulative number of farmers keeping livestock and total number of livestock. Livestock include cattle, horses, sheep, goats, and pigs.

17. THE EFFECT OF AGROCHEMICALS ON VECTOR POPULATIONS[1]

George P. Georghiou[2]

Introduction

Crop losses due to the action of herbivorous arthropods, parasitic fungi, nematodes, molluscs and noxious weeds have been estimated to represent at least one-third of production (Cramer, 1967). Losses from insects alone were stated to amount from as low as 12% of potential production (Univ. of California, 1974) to several times that much (Pimentel **et al.**, 1978). Modern plant protection chemicals offer the most practical means of reducing crop losses, and demand for these will continue to rise as developing countries strive to increase their agricultural production. The world market for pesticides in 1985 was estimated at $13,778 million and is expected to increase to $15,759 million by 1990 (Farm Chemicals, 1985).

Insects of medical importance, especially mosquitoes, are often found breeding in agricultural habitats and are hence exposed to the insecticides employed in agriculture. It is estimated that 90% of all insecticides produced by industry are used for agricultural purposes, with cotton and rice receiving the greatest share of these chemicals (WHO, 1986). Aerial application of insecticides, especially by ultra-low volume, is known to result in some drift into surrounding areas, even under optimal meteorological conditions (Yates **et al.**, 1978). These treatments may be expected to suppress mosquitoes in that environment, but, when occurring repeatedly, could also lead to development of resistance to insecticides.

Reports from various parts of the world indicate that mosquito resistance has been more severe in areas where crops are treated frequently with insecticides. Although some of the evidence is circumstantial, an increasing body of information points to a direct cause-effect relationship between the use of insecticides in agriculture and serious problems in mosquito control. The writer established a close correlation between the type and quantities of insecticides applied in cotton-growing areas of El Salvador and Nicaragua, and the presence of resistance to insecticides in **Anopheles albimanus** (Georghiou, 1972). The dilemma arising from this problem has been discussed in historical perspective by Garcia Martin and Najera-Morrondo (1972), and in economic and sociological terms by Chapin and Wasserstrom (1981). The subject has also been reviewed by the writer (Georghiou, 1975, 1976, 1982), and by WHO (1986). The present paper represents an extension and updating of the material of those earlier reviews.

Toxicity of agrochemicals to vectors

Most agricultural insecticides are nonspecific; they are toxic to agricultural pests as well as to vectors and their predators. Numerous data in the published literature confirm the considerable potential of agricultural insecticides to suppress mosquitoes, larvae as well as adults, and their predators, through direct toxicity (reviews by Mulla and Mian, 1981, Mulla **et al.**, 1979).

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1 This paper will also be published, in a modified version, as a chapter in: Pesticide Resistance in Arthropods, Roush, R.T. and Tabashnik, B.E. (Eds.), CRC Press

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1100

Other pesticides, e.g., herbicides, fungicides and molluscicides, appear to possess limited toxicity to insects at the concentrations in which they are employed in the field. Certain herbicides are synergistic of insecticides against mosquito larvae. For example, diquat and related one-electron transfer agents produce significant synergism of propoxur and fenthion to **A. albimanus** and **C. quinquefasciatus**, possibly by inhibition of microsomal detoxification systems. However, the concentrations of herbicide needed for synergism far exceed those applied for weed control (Georghiou **et al.**, 1974). The impact of agricultural fungicides on fungi that are parasitic on vectors does not appear to have been adequately investigated. Thus the following discussion applies only to the effect of agricultural insecticides with emphasis on the development of resistance by mosquitoes.

Evidence for implication of agrochemicals in vector resistance

The evidence for implication of agricultural insecticides in vector resistance is in most cases indirect and circumstantial. Many reports point out either that the problem of vector resistance exists in agricultural areas that are heavily treated with insecticides, or that mosquito populations are more resistant in agricultural than non-agricultural areas even when both areas have received an equal number of treatments by public health authorities. While some of this information may be convincing enough, definitive evidence comes only from a small number of documented cases, especially those involving **Anopheles albimanus** in Central America (Georghiou, et al, 1971, 1973, 1974; Georghiou, 1972; Hobbs, 1973; Ariaratnam and Georghiou, 1974, 1975; Ayad and Georghiou, 1975, 1979; Bailey **et al.**, 1981).

1. Appearance of vector resistance prior to the application of chemicals against vectors.

Dieldrin resistance was present in **A. sacharovi** and **A. maculipennis** in Turkey in many agricultural areas in which neither BHC nor dieldrin had been used for vector control (Ramsdale, 1973). In the delta area of Egypt, where cotton was treated extensively with toxaphene and DDT, marked resistance to dieldrin and incipient resistance to DDT were noted in **A. pharoensis** in 1959 prior to the commencement of residual house spraying (Zahar and Thymakis, unpublished report to WHO, 1962). Similar occurrences of resistance were reported for dieldrin in **A. maculipennis** in Romania (Duport, 1965), **A. aconitus** in the Malang district of East Java (Brown and Pal, 1971), in **A. gambiae** in Mali (Hamon **et al.**, 1961), and in the lower Volta region of Ghana (W.Z. Cocker, cited in Hamon and Garrett-Jones, 1963).

2. Higher vector resistance in agricultural than in non-agricultural areas.

Frequently cited are reports of the presence of mosquito resistance in agricultural areas and its absence, or presence at lower levels, in non-agricultural areas, although both had received residual house spraying. Thus, in Greece, Belios (1961) found higher dieldrin and DDT resistance in **A. sacharovi** in the cotton- and rice-growing area of Laconia than in Etolia and Euboea, a fact which he attributed to strong selection pressure on the larvae by agricultural insecticides.

In Turkey, Ramsdale (1973, 1975) pointed out that although DDT had been widely used for more than 20 years in public health and agriculture, the incidence of DDT resistance was not related to the duration of DDT house spraying operations: more than 10 years of regular house treatment had not affected the susceptibility of **A. sacharovi** or **A. maculipennis** in the southeastern part of the country. However, remarkable DDT resistance had developed in the cotton-growing district of Manan, Adana (M. H. Holstein,

cited by Brown and Pal, 1971). Similarly, in Pakistan it was noted that the incidence of malathion resistance in **A. stephensi** coincided to a large degree with the geographic distribution of cotton cultivation (Georghiou, 1986).

Considerable differences in the susceptibility to OP and carbamate insecticides in **A. albimanus** from different areas were reported by Georghiou **et al.**, (1971): strains from Haiti, where agricultural use of these insecticides was minimal, were of normal susceptibility, whereas strains from the cotton- and rice-growing areas of El Salvador showed remarkable levels of OP and carbamate resistance. Such differences were apparently not due to the extreme geographical separation of these populations since a strain from the isolated area of Texistipeque, Santa Ana, El Salvador, which had not experienced commercial use of OP or carbamate insecticides, was equally susceptible to propoxur and DDT as was the strain from Haiti (Georghiou, 1972).

3. Correlation between intensity of insecticide use on crops and degree of resistance in vectors.

Studies in Central America showed correlations between the intensity of pest control operations on cotton and rice and the degree of OP and carbamate resistance in **A. albimanus** (Georghiou, 1972). In these areas, cotton crops are treated with insecticides at frequent intervals, as many as 30 applications being made during the 6-month growing season. As a result, resistance of cotton pests to chemicals has been an extremely serious problem in this region. According to Smith (1968), problems of resistance to insecticides in Central America cotton insects "have usually started first in El Salvador".

An extensive field survey of susceptibility of **A. albimanus** in Nicaragua, Honduras, El Salvador and Guatemala in 1971, showed evidence of significant resistance to carbamates (propoxur) and to OP's (malathion and parathion) in the Department of La Paz, El Salvador, and in the Sebaco Valley, Nicaragua. Lower resistance levels, or absence of resistance, were obtained elsewhere in these countries (Georghiou, 1972). Examination of the available agronomic and pest control information in El Salvador indicated that the higher resistance in La Paz was in agreement with the more intensive chemical pest control that was practised on cotton and rice in that Department as compared to other Departments of the country. No information could be obtained on the quantities of insecticides used per acre in each Department. However, calculations from data provided by the Ministry of Agriculture indicated that 26% of the country's cotton acreage was found in the Department of La Paz. Here, the average holding per cotton grower was 81 hectares as compared to 23 hectares per grower in the remainder of the country. There were indications that the larger the holding the greater the tendency to apply insecticide treatments on a fixed schedule rather than discriminately when and where needed. Eighty-seven percent of the cotton acreage of El Salvador was treated by aircraft, a practice that may result in frequent contamination of mosquito breeding habitats. In the Department of La Paz 95% of the acreage was treated by air, and approximately one-fifth of this was treated by ULV sprays.

As with cotton, rice cultivation in El Salvador was also more intensive in La Paz. During 1969-70, 53.6% of the rice acreage of the country was in the central part of the coastal plain, including La Paz, as compared to 25.5% in the western and 20.9% in the eastern parts.

Intensive use of insecticides, especially on rice and cotton, was also practised in Nicaragua. Complete reliance on chemical control of rice pests led to a spiraling number of insecticide applications. On one large farm at La Concepcion, on which rice growing began in 1963, the following treatments had been applied up to 1971:

Year	Insecticide applications	Total
1963	none	0
1964	carbaryl (4)	4
1965	carbaryl (6)	6
1966	carbaryl (3); carbaryl + methyl parathion (4)	7
1967	monocrotophos (2); carbaryl + methyl parathion (7)	9
1968	monocrotophos (3); endrin (2); disulfoton ethyl/methyl parathion (2)	8
1969	perthane (1); monocrotophos (2); endrin (2) naled (3)	8
1970	perthane (1); naled (2); benfucard (3); methamidophos (2)	8
1971	naled (3); benfucarb (3); methamidophos (3); diazinon (1)	10
1972	changed to sorghum	

As in the case of OP and carbamate resistance, DDT resistance has also occurred at higher levels in the cotton-growing area of Nicaragua.

Additional evidence of the impact of agricultural insecticides is revealed by a study of OP multiresistance in populations of **Culex quinquefasciatus** in California (Georghiou **et al.**, 1975). Strains collected from dairy waste drains of two farms located six miles apart in the intensely agricultural Central Valley revealed significant differences in the levels of OP resistance. Both breeding sites had experienced similar larvicidal treatments which, in 1973 and 1974 consisted exclusively of chlorpyrifos. However, examination of the official records of agricultural insecticide applications within a three-mile radius of each farm indicated that during 1971-74 approximately twice as large a quantity of OP and carbamate insecticides had been applied in the area of the more resistant population.

4. Fluctuations of vector resistance in parallel with periods of agricultural spraying.

A study conducted over a two-year period (1970-72) in the cotton-growing area of El Salvador indicated that the susceptibility levels of **A. albimanus** showed seasonal fluctuations in parallel with the period of spray applications to cotton. Sampling was done in June and February of each year, i.e., at the beginning and end of the cotton-growing season. Resistance to parathion, methyl parathion, malathion, fenitrothion, carbaryl and propoxur was found to rise during the spray period and to decline somewhat during the non-spray period. With reference to a susceptible strain, the resistance levels observed (at the LC50) were: malathion 117x, parathion 158x, methyl parathion 144x, fenitrothion 45x, propoxur 1000x, and carbaryl 443x (Georghiou **et al.**, 1973).

5. Correspondence between the spectrum of resistance in vectors and types of insecticides applied to crops.

The El Salvador studies of 1970-73 have also indicated that the spectrum of multiresistance in **A. albimanus** can be traced to the types of insecticides applied to cotton. Parathion and methyl parathion were the principal insecticides used on this crop for over a decade, and have clearly had the greatest impact on **A. albimanus**, as reflected by the high resistance levels to these compounds. The elevated resistance to malathion may have resulted from the relatively limited malathion treatments, with

additional selection of malathion-resistant genotypes by other OP's. Carbamate resistance may be the consequence of carbaryl applications and to a lesser extent of propoxur, such resistance being supported and enhanced further by OP selection pressure. This suggestion has been validated by biochemical tests, which revealed that OP (parathion) and carbamate (propoxur) resistance in this mosquito is due to the selection of a variant acetylcholinesterase that is far less sensitive to inhibition by these compounds (Ayad and Georghiou, 1975, Hemingway and Georghiou, 1983). This property is encoded by a single gene which may also be responsible for the high resistance toward other OP's and carbamates (Georghiou **et al.**, 1975).

6. Temporary suppression of vector population densities in sprayed areas.

Suppression of mosquito populations by agricultural insecticide applications was clearly demonstrated by Hobbs (1973) in El Salvador. Adult **A. albimanus** densities began to build up in May following the onset of the rainy season. However, whereas in a non-cotton area the density remained relatively high throughout the rainy season, in a cotton growing area it fell abruptly in mid August and remained low until December. This decline coincided with the increased application of insecticides to cotton. In the same study, 16 larval breeding sites within the cotton area were negative at the end of August and remained so until December. The single exception that remained continuously positive was a cattle watering pond, situated at the limit of the cotton district.

As expected, continued severe selection pressure eventually resulted in the evolution of such high resistance that the mosquito population could no longer be suppressed effectively by agricultural sprays. This was demonstrated by a study conducted five years later in the same area of El Salvador (Bailey **et al.**, 1981). Standardized collections were made at weekly intervals from June 18, 1977 to March 25, 1979 at several sites within the cotton area as well as at sites located at least one km away from cotton fields. The data show that the adult mosquito population within the cotton area was suppressed only mildly by the first treatments and that its density recovered steadily so that by the end of the spraying season it had reached a level similar to that observed in the non-cotton area. Roughly similar results were obtained by larval counts. It was thus obvious that through continued yearly selection and intermingling of the population of the sprayed and non-sprayed areas a uniformly resistant population had evolved whose density was could no longer be drastically suppressed by the agricultural pest control treatments. A similar situation was reported for **C. tritaeniorhynchus** in the Republic of Korea and Japan. Here widespread use of insecticides on rice was introduced in 1966. This led to good control of the species up to the end of the 1970's when it developed resistance to all insecticides used for agricultural purposes. As a result, populations of this species can no longer be controlled by agricultural pesticide applications (WHO, 1986).

Discussion

The available evidence leaves little doubt that agricultural insecticides, when applied over a wide area, are capable of exerting strong selection pressures against mosquito populations. Such selection could be the result of decimation of the adult population, suppression of larvae by contamination of breeding habitats, or both.

In Central America, selection occurred with regularity from August through December, as shown by in the large number of spray flights carried out and the nearly complete suppression of mosquito populations. Such selection resulted in the development of resistance, which rose annually to higher levels in concert with the seasonal spray/non-spray periods. Resistance was quantitatively congruent with the intensity of agricultural operations in each area, and qualitatively indicative of the compounds that were employed. The resulting multiresistance has considerably reduced

the efficacy of residual applications of propoxur, malathion, and fenitrothion with a concommitant resurgence of malaria transmission.

The possibility that public health applications of insecticide may contribute to the development of resistance in mosquitoes cannot be excluded. In most cases, however, residual house spraying alone, as applied for malaria control, exerts selection pressure on no more than 50% of the population, since mostly female mosquitoes enter houses. This proportion would be even smaller in rural, sparsely populated areas, and where the vector is partly exophagic, as with **A. albimanus**. Under these conditions, the possibility of resistance due to these treatments alone must be minimal. In India, **A. minimus**, a highly endophilic species that is not directly exposed to the impact of agricultural insecticides has not developed resistance after 20 years of house spraying (WHO, 1986). Where larvicides are used, especially in combination with adulticides, a higher degree of selection pressure is exerted, particularly if the same or related chemicals are used. Exposure to both agricultural and public health treatments enhances further the prospects for resistance development. In the case of **C. quinquefasciatus** referred to earlier, it was concluded that the large variety of insecticides applied to crops had predisposed the population to respond readily to the specific selection pressure applied by chlorpyrifos at the breeding sites.

In searching for alternatives to alleviate this problem, two points of concern must be borne in mind. Firstly, in many developing countries, the introduction and use of insecticides in agriculture remains unrestricted and unregulated. New compounds are introduced before they have been fully tested and licensed. In contrast, their use in public health, especially for residual house spraying, is preceded by exhaustive testing, requiring several years for completion. Since the same compounds are usually candidates for both agriculture and public health, their earlier availability and use in agriculture jeopardizes their subsequent effectiveness against mosquitoes due to resistance.

A second concern is the exposure of mosquitoes to the multitude of insecticides applied in agriculture. Exposure to compounds of varied chemical nature, appears to select in favour of several pathways of detoxication (or "site insensitivity"), thus preparing the mosquito population to respond more readily to the specific selection subsequently applied against mosquitoes.

18. INTEGRATED PEST CONTROL STRATEGIES IN FOOD PRODUCTION AND THEIR BEARING ON DISEASE VECTORS IN AGRICULTURAL LANDS

M.J. Way[1]

Introduction

Intensive use of agricultural pesticides, notably insecticides, since the 1950s has led to widespread and serious problems of induced resistance, pest resurgences, induction of new pests, poisoning of humans and domestic animals, and also harm to wildlife in general. Such problems arose predominantly in relation to high technology agriculture in developed countries, and at a time when chemicals were relatively little used on basic food crops or even on many cash crops in developing countries. Yet already there was much evidence of human poisoning and of pesticide-induced crop pest problems in developing countries. Recognizing that pesticide misuse can potentially create particularly serious problems in tropical climate conditions, FAO established a Panel of Experts on Integrated Control in 1967, with the fundamental objective of helping define and put into practice relevant methods of pest management in developing countries. Subsequently, it became a joint FAO/UNEP Panel.

At the time when the Panel was set up, the term "Integrated Pest Control" (Stern **et al.**, 1959) had been firmly adopted by agricultural entomologists as a rational approach to pest control instead of the over-reliance, sometimes total reliance, on synthetic pesticides. Integrated pest control, now synonymous with "Integrated pest management", is a broad ecological approach to pest (animals, diseases and weeds) control, using a variety of control technologies compatibly. The fundamental principle is that whilst chemical pesticides may be essential, they should be used to complement rather than jeopardize controls based on host plant resistance, cultural practices and use of natural enemies. At the most practical level integrated pest control can be defined as "the best mix of available tactics for a given pest problem in comparison with the yield, profit and safety of alternative mixes" (Kenmore **et al.**, 1985)

Integrated control is now widely recognized as an objective in pest control in agriculture and public health as well as in all other situations where harmful organisms need to be controlled. The general approach in vector control has often been discussed and defined, e.g., by Axtell (1979), Laird (1986), Laird and Miles, (1985) and most recently by Schaefer and Meisch (1987) - "the inclusion of all available control methodologies in an optimised combination". So, the basic principles are similar for both agriculture and public health (Franz **et al.**, 1985).

Integrated control in agriculture has been most readily conceived and adopted against one or very few key pests on a particular crop. A sensible integrated control programme for a complex of crop pests is a much more formidable prospect, and is complicated even further by extending it to integration between disciplines such as crop pest and human disease vector control. No doubt this helps explain why in the many textbooks, conference proceedings and publications on integrated pest control in agriculture there is little more than general reference to links with public health problems even in situations where there is obvious need for integration. Little or no attempt seems to have been made to bring together specialists to examine how the control of agricultural pests and of vectors might be mutually benefited, not even in the

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workshop at IRRI in the Philippines as recently as March 1987, on "Research and Training Needs in the Field of Integrated Vector-borne Disease Control in Riceland Agro-ecosystems of Developing Countries". Papers for this meeting, sponsored by IRRI, PEEM and USDA, refer only in general terms to the problem of integration with agricultural research and development work, although perhaps more definite proposals were made at the workshop discussions.

Interaction between crop pest control and incidence and control of vectors

Agricultural developments with their emphasis on increased yields through high yielding varieties, fertilizers and improved water supply have greatly exacerbated many crop pest problems in the tropics, because host plant resistance has often been traded for yield potential in breeding programmes, fertilizers make plants more nutritious for pests, and irrigation also permits continuity of pest generations and hence build-up of pest populations. This has led to the increasing use and dependence on chemical pesticides, which in turn has exacerbated problems through destruction of natural enemies and through direct effects on the host plant, making it more susceptible to certain insects. It is therefore inevitable that the massive increases in use of chemical insecticides against crop pests during the last 20 years will influence disease vectors that live in the sprayed habitats. Surprisingly, little critical work has been done on this problem. Georghiou **et al.** (1973) referred to observations since 1966 in Central America which suggested that the malaria vector **Anopheles albimanus** was developing resistance from indirect exposure to agricultural insecticides. This classical paper (also: Georghiou, 1986) demonstrated induced mosquito resistance to a range of organophosphorus and carbamate insecticides associated with the agricultural spray period (August-January) on irrigated cotton fields and declining somewhat during the non-spray period (Fig. 1). These changes were most pronounced with carbamate insecticides (e.g., propoxur). This work, as well as some evidence from elsewhere (Georghiou, 1976), confirmed that agricultural pesticides, particularly those used in mosquito breeding areas, such as rice paddies, could seriously jeopardize chemical control of some malaria vectors. The evidence led to decisions, for example in 1977 in Sri Lanka, to restrict the use of malathion and fenitrothion to malaria control in an attempt to minimize development of resistance in malaria vectors that could be caused indirectly by their agricultural use notably against insect pests of rice. This is in part a detailed study of indirectly induced resistance in **Anopheles subpictus**, **A. nigerrimus** and **A. culicifacies** of which the latter is the primary malaria vector in Sri Lanka (Hemingway **et al.**, 1986, 1987). **A. subpictus** and **A. nigerrimus**, which breed in rice paddies, show resistance to a range of organophospate and carbamate insecticides used against rice pests, which cannot be attributed to chemicals used against mosquito vectors in houses, since one species, **A. nigerrimus**, is exophilic, while one of the major resistance genes in the other confers no resistance to the insecticides used for house spraying. In contrast, the endophilic **A. culicifacies** showed resistance only to malathion and closely related compounds associated with house spraying against the adults. In Sri Lanka **A. culicifacies** breeds in slow-moving streams and pooled river beds and not in rice fields. Moreover, Hemingway **et al.** (unpublished manuscript) have shown that residues of the organophosphorus and carbamate insecticides used against rice pests had dissipated by the time they reached the breeding habitats of **A. culicifacies**. This work demonstrates the importance of understanding the significance of breeding and resting sites of disease vectors relative to where agricultural pesticides are used and to persistence of residues in run-off from the sprayed areas.

The density of the vector in sprayed areas relative to unsprayed areas must be very important. In El Salvador, for example, the rise and fall of resistant **A. albimanus** (Fig. 1) in spray and non-spray seasons, respectively, might suggest dilution by susceptible mosquitos from unsprayed areas during the non-spray season. However, the general level of resistance increased strikingly in successive years, associated with

heavy selection pressure from up to 30 insecticide applications on cotton in El Salvador during the six-month season. Whilst indirectly induced resistance is a very serious hazard, it must also be appreciated that agricultural insecticides can drastically decrease vector populations locally, and perhaps usefully (Fig. 2) (Hobbs, 1973; Service, 1977).

Similarities and differences between the integrated control approach against agricultural pests and disease vectors

The general principles of integrated pest control represent common sense, so are widely agreed. Successful application requires critical examination of the methodologies, individually and collectively, in terms of efficacy and then practical viability. Individual methodologies for vector control have been broadly classed under three main headings (e.g., Axtell, 1979): - "chemical", "biological", and "environmental management". Agricultural pest control methodologies can be classed similarly, with environmental management including "cultural control".

* Biological control. Even in the 1950s (Ripper, 1956) much evidence of insecticide induced resurgences of pests and the appearance of new pests caused by pesticides provided striking proof that many insect pests of crops are usefully limited by natural enemies, and also that many potential pests remain harmless because they are controlled by natural enemies. Consequently, the original definition of integrated control (Stern, **et al.**, 1951) stressed the need to use pesticides selectively in ways which minimised harm to natural enemy action. The emphasis was on true integration, not on merely using a mix of methods. In agriculture, as in vector control, biological control is envisaged as being accomplished by naturally occurring species as well as by various forms of introduction, ranging from temporarily acting repetitive inundative releases to single releases giving prolonged benefits and even permanent control (Waage and Greathead, 1987).

Natural enemies, especially parasitoids, seem to be recognized as being relatively less important against some major vectors such as mosquitos (Service, 1977; Laird, 1986; Laird and Miles, 1985), though maybe vector control specialists still underestimate them as components for integration that should not only be maintained but strengthened. Even in agriculture it is relatively uncommon for biological controls to invariably prevent pest damage, but there is much continuing evidence, since Ripper (1956), that disregard of the biological control component can lead to catastrophies and at least to an unnecessary increase in the use of chemicals.

Seemingly, human vector-borne disease control requires a much greater reduction in vector numbers than would be acceptable for many agricultural pests. Whilst this militates against both naturally occurring and introduced biological controls (with the exception of biological insecticides such as **Bacillus thuringiensis**), as predominant means of control it does not justify less emphasis on them in vector control, at any rate in ecological conditions where natural enemies flourish, i.e., where breeding sites are not highly ephemeral. Not only can their impact put less "demands" on a subsequent chemical treatment, but after the treatment their action on "residues" of resistant pests must assist in delaying development of resistance in pests (Way and Cammell, 1985).

Studies on biological control that need to be carried out include the identification of natural enemy species that are common to crop pests and vectors in particular habitats. And another question to be answered is: how do certain natural enemies interact, for example, can vertebrate predators, especially introduced ones, prey on and thereby impair the action of important arthropod natural enemies of crop pests and vectors?

* Host resistance. Another critical difference between biological approaches toward control of agricultural pests and vectors is the role of host resistance. Although there is evidence of human host resistance to disease, there is no equivalent to the breeding for crop host resistance that is sometimes invaluable in crop pest integrated control strategies. Even small amounts of resistance can be important because this allows other controls to make a greater impact (van Emden, 1987), e.g., crop host resistance, by multiplication of a pest, favours natural enemy action as well as lowering resistance of the target pest to pesticides.

It should be recognized that characteristics of host plants including those chosen for resistance to pest could favour or be detrimental to adult or larval vectors (Service, pers.comm.).

* Environmental controls. Environmental management in agriculture includes powerful cultural controls based on manipulating crops in time (e.g., varying sowing dates) and space (e.g., varying the crop pattern), and on comparable manipulation of "spacing" and density of domestic animals. Such tactics are not directly relevant to human vector control, but need to be carefully examined because, for example, methods of planting and rates of canopy closure of rice are known to affect mosquito species. However, the manipulation and "spacing" of domestic animals to help control pests and diseases is analogous to many important problems of human diseases associated with the proximity to domestic animals.

Whilst there are notable differences in relative value of and emphasis on the different methods for vector and agricultural pest controls, their interactions must be examined. Just as insecticides used against different pests can directly or indirectly affect each other, so can different environmental manipulations for agricultural pests and for vector control, either beneficially or detrimentally. Besides direct effects of environmental manipulations on target crop pests or vectors, they also act indirectly through their actions on natural enemies. Environmental manipulation is therefore actually and potentially very important in influencing natural enemy action, as shown by the following case history concerning the riceland ecosystem.

The development of the integrated control approach against rice pests

Rice was not often seriously damaged by pests until the introduction, by the "green revolution", of a package of technology: high yielding cultivars, artificial fertilizers and improved irrigation, which in some areas allows up to three crops a year and year-round continuous cropping. These inputs have greatly increased damage by insect pests, so chemical insecticides are also an essential part of the package. Insecticides have proved invaluable in protecting rice, but characteristically have also created resurgences and hence accelerated dependence on pesticides. In particular, a new pest, Brown Planthopper (BPH) **Nilaparvata lugens**, was created (Fig. 3), which is now the most serious pest of rice in much of South-East Asia (Heinrichs and Muchida, 1984), though rice breeding for resistance to BPH has partly alleviated this problem in some areas.

It is evident that BPH, at any rate in the tropics, is normally kept under control by a large guild of generalized predators which also act against other pests or potential pests. Different kinds of insecticides have caused rapid resurgences leading to major outbreaks of BPH through destruction of its natural enemies (Fig. 3; Kenmore **et al.**, 1985) enhanced by the insecticide also directly altering the rice plant physiology, increasing its nutritiousness, and so encouraging a pest multiplication rate beyond natural enemy control (Heinrichs and Michida, 1984). The same considerations apply variously to other rice pests.

Impending disasters from green revolution technology led to rice being highlighted by FAO through its FAO/UNEP Panel of Experts on Integrated Control which stimulated a Cooperative Programme on Integrated Pest Control in South-East Asia. This involves FAO/UNEP coordination of joint action by rice pest control specialists in major rice producing countries in South-East Asia and also publication of guidelines (FAO, 1979). As with all such control programmes, the vital first step has been to limit insecticide usage to when it is justified on the basis of an economic injury threshold (Kenmore, 1987). This includes defining levels of pest numbers that if unchecked by chemical treatment would lead to losses greater than the value of the treatments applied. Such an approach not only prevents wastage of insecticide but also minimises harm to beneficial species. The definition and utilisation of economic injury thresholds for such pests, combined with the selective use of insecticide is considered fundamental to integrated control of crop pests (Way, 1977). The economic threshold concept seems comparable to the "cost-benefit approach" in vector control where it seems much less definable or applicable than the notably different concept of "cost-effectiveness" (WHO, 1986).

The FAO/UNEP Programme has established working economic injury thresholds and recommended suitable insecticides, its current priority being on their adoption by farmers (Kenmore, 1987). With reference to Mather's (1984) "problem of convincing agriculturalists that new ideas are viable" for vector control by environmental management, the enlightened approach of this programme (Kenmore, 1987; Kenmore **et al.**, 1985) may provide insights on how vector control strategies might also be more effectively encouraged by government decision makers and adopted by farming communities.

Questions to be asked include how such current development in integrated pest control for rice can affect the status and control of vectors associated with rice fields and how strategies might be modified to be mutually compatible. Obviously, reduction in pesticide usage will decrease resistance inducing pesticide pressure on the vector, but what are the other possible effects?

* Biological control. Does lessened and selective application of pesticides against rice pests benefit natural enemies of vectors and, anyway, does this matter? Some detailed studies of natural enemies of mosquitos in rice fields have been undertaken, for example by Service (1977) in Kenya, and by Mogi **et al.** (1980a, b) in Japan. In Kenya, about 30 species of predators of **A. gambiae** occurred in rice fields, the most important belonging to the Amphibia, the Odonata and the Coleoptera. Service estimated that larval mortalities of up to about 93% occurred in rice fields to which predators made an important contribution. Mogi **et al.** also concluded that the approximately 96% loss of **C. tritaeniorhynchus** larvae during development was primarily due to predation by fish, Odonata, Notonectidae and Discidae.

In Kenya, field spraying with dimecron against a rice stem borer obliterated both the current **A. gambiae** larval population and the predators, but 14 days later the **A. gambiae** population had risen to above pre-spraying levels, whereas the predator population had remained at its low level (Service, 1977). Despite what appears to be very important natural enemy induced mortality, Service (1977) concluded that, in the Kenya situation, this probably had little effect on disease transmission by the **A. gambiae** vector, which would remain unaffected even by a 1000-fold reduction of the vector population. However, although natural enemy mortality may be relatively unimportant in the Kenyan case, this cannot be assumed to apply to other situations where the vector is not so super-abundant. First, it should always be remembered that mortalities, as caused by predators, that cut across insecticide selection pressure, must be important in preventing or delaying development of resistance (Way and Cammell, 1985). Apart from this there is a need as pointed out by Service (1985) and in Laird (1983, 1986) and Laird and Miles (1985) to intensify relevant ecological work on vector biocontrol agents, both naturally occurring and applied. Crucial tests would include critical examination of situations where insecticides are or can be used selectively.

Bacillus thuringiensis serotype H-14 can provide selective control of mosquito larvae, so seemingly would do relatively little harm to most of its predators or to predators of agricultural pests. The main problem in such circumstances would be adequate selectivity of chemicals for rice pest control. At present the integrated pest control strategy for rice is to integrate host plant resistance to some pests with threshold-based use of relatively selective chemicals against others. Such studies against the rice pests should include examination of how relevant practices can affect mosquitos and their predators and how they might be manipulated to mutual advantage. This should not be too difficult and it would undoubtedly provide an experimental starting point for an integrated crop pest/vector control programme.

* Environmental management. Environmental management in the form of cultural controls is widely accepted as very important, or potentially very important, in integrated rice pest control. The many methods (e.g., Lim and Heong, 1977; FAO/UNEP, 1982) include, in particular, manipulation of planting and harvesting dates and water management, all of which could also influence mosquito breeding and survival. Synchronous planting and harvesting are highlighted as a means of creating off-season area wide breaks in cropping which dislocate the life cycle of rice pests instead of a patchwork of fields planted at different times which provide a continuous sequence of crops for build-up of pests (Perfect, 1986; Loevinsohn, 1984). Synchronous planting with periodic area-wide non-crop unirrigated phases must also dislocate the breeding sequence of vectors.

Not only is synchronous planting likely to dislocate the life cycle of a pest and of a vector, but, in practical terms, it is particularly important in permitting synchronised insecticide applications giving area-wide reduction of overall pest populations. This has been widely adopted in countries such as Japan for rice pest control and can apply equally to control measures aimed at chemical control of vectors (e.g., Mogi, 1984, 1987).

Techniques of water management during the cropping season based on periodic drying off or flooding are also recommended against important hemipterous pests such as **N. lugens** (FAO/UNEP 1982). These procedures would seem to be equivalent to recommended vector control based on "intermittent" or "wet" irrigation (Mather, 1984; Lu Bao Lin, 1987).

Clearly, there is a vital need to examing planting methodologies and water management aimed at simultaneously helping control of both rice pests and the vectors that breed in the rice fields. In terms of a biological control component of integrated control there are however potential dilemmas because techniques which dislocate the life cycle of a pest may also disturb a pest/natural enemy equilibrium on which effective biological control by native natural enemies may depend. So, in theory, a patchwork of fields planted at different dates is more likely to maintain such stability, whereas area-wide off-seasons when there is neither crop nor water, or even temporary drying out or flooding during growth of a single crop must surely do serious harm to the natural enemy complex. The only answer is enlightened research and to join the plea by Mogi (1981) to "invest heavily in larval ecology studies without further delay".

Discussion and conclusion

Worldwide, rice is outstanding in providing conditions where agricultural needs and those of human disease vector control interact most strongly, and so provide special justification for examining their integration. Comparable situations also occur with other major disease problems, notably schistosomiasis. In contrast, the control of

tsetse as a vector of human sleeping sickness and domestic animal diseases, involves strikingly different ecological and economic criteria. Here, particularly in dry-land areas of Africa, agricultural developments, rather than exacerbating the vector-borne diseases, can decrease them concomitantly upsetting the habitat of the vector (Jordan, 1974).

While it is evident that similar principles apply to the integrated control of crop pests and of vectors, this is not especially helpful in terms of practical action other than by providing a common conceptual background. This paper uses rice as an example to highlight some practial opportunities based on appropriate research development work on integrated crop pest and vector control. Conclusions and recommendations on different component methods are the following:

(1) Environmental controls based on planting and irrigation practices

Dates of planting, sequential planting, and intermittent irrigation regimes all affect both pests and vectors. It is recommended that a more detailed analysis be made of how the two kinds of damaging organisms are affected. From this should come practical recommendations on situations where research and development work should be done to optimise mutual benefits for pest and disease control. Guidelines should be produced on combinations of environmental controls for rice pests and vectors which could provide a basis for work on appropriate local modification.

(2) Role of natural enemies, particularly naturally occurring species.

The natural enemy complex, notably generalized predators, can cause mortality of some rice pests and of vectors breeding in rice fields. Much more work is needed on the mortalities they cause in different conditions, on the important predator species, on those that are common to both crop pests and vectors, on how they are affected by environmental manipulations, and how they might be benefited in other ways than by merely avoiding use of the more harmful pesticides. This involves detailed and difficult research and perhaps calls for the initial work to be localised in one or two object-lesson situations.

(3) Use of pesticides, in particular of insecticides.

There is a clear need to review knowledge of the selective use of insecticides in rice fields in relation both to crop pests and vectors. Such a review should include recommendations on future research and development work, and should also examine herbicide usage, since herbicides can affect natural enemies both directly, or indirectly, for example by depriving predators of alternative prey that depends on certain weeds. Moreover, some herbicides can help select for insecticide resistance either on their own, or in combination with other pesticides (Hemingway, pers.comm.).

(4) Implementation of integrated control procedures.

It must be admitted that integrated pest controls based on elegant integration of different methods are practised in very few crop pest situations (Way, 1977). Many active programmes have this ideal as an objective but are still struggling with the earlier stages of practical application including use of economic injury thresholds, decision making on insecticide application and choice and methods of application.

Part of the problem stems from the fact that in many of these projects an interdisciplinary approach is not adopted. Such attempts to achieve improvements in integrated pest control are founded solely on biological integration rather than on

integrating biological, technical, socio-economic and other important features of the farming or cropping system. Although the "Farming Systems" approach is helping to proselytise this idea, there is still a need for developing and applying more detailed and appropriate systems analysis techniques (Norton, 1987) to help implement the practical pest management approach. Here the philosophy is first to define the problem in terms of current farmer practices and then search for improvements within that context: a problem-oriented rather than a solution-based approach. This general approach would seem to be applicable to vector control.

In terms of biological approaches, environmental (cultural) controls are a vital part of many crop protection systems but integration remains incomplete, and the approach to biological control remains largely that of avoiding harm to naturally existing agents rather than simultaneously boosting their action, except in situations where biological agents are used essentially as biological pesticides (e.g., **Bacillus thuringiensis**, some virus diseases of pests and some inundative releases of arthropod natural enemies). In rice pest control, as in the FAO/UNEP programme, integrated manipulations of environmental controls and control by natural enemies are at an early stage of development, and are complicated by the fact that requirements differ in different localities (e.g., Lim and Heong, 1977), so locally specific tactics are needed.

The approach outlined by Schaefer (1987) for integrated vector control fits closely with that adopted under the FAO/UNEP Programme for Rice Pest Control (e.g., Talib Majid **et al.**, 1985). Schaefer (1987) emphasises key problems for initiating integrated mosquito control in rice fields including vector monitoring, definitions of tolerance levels and selective chemical controls when needed, all based on a better knowledge of relevant ecology of vectors and of coexisting biological control agents.

Much complementary research therefore remains to be done on crop pest/vector controls, but, even so, there are already opportunities for practical application. The enlightened approach by the FAO/UNEP Programme to government and farmer acceptane and implementation of the early phases of integrated pest control in rice (Kenmore **et al.**, 1984) has already been referred to as providing insights for those concerned with vector control - e.g., to help solve "the problem of convincing agriculturalists that new ideas are viable" (Mather, 1984). It would therefore be seen very desirable for vector control specialists to link appropriately with the FAO/UNEP integrated pest control programme.

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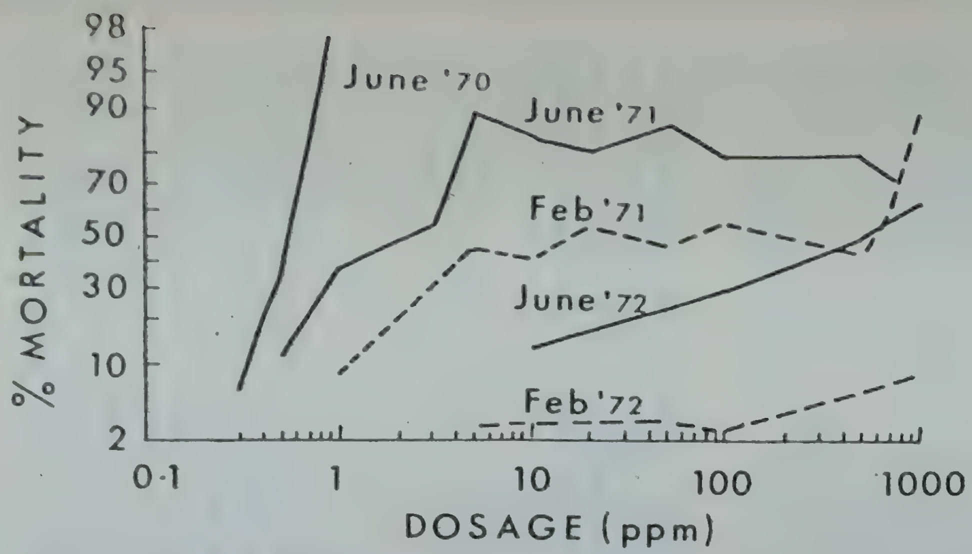

Fig. 1. Seasonal fluctuations in resistance of A. albimanus to the carbamate propoxur (Georgiou et al., 1973).

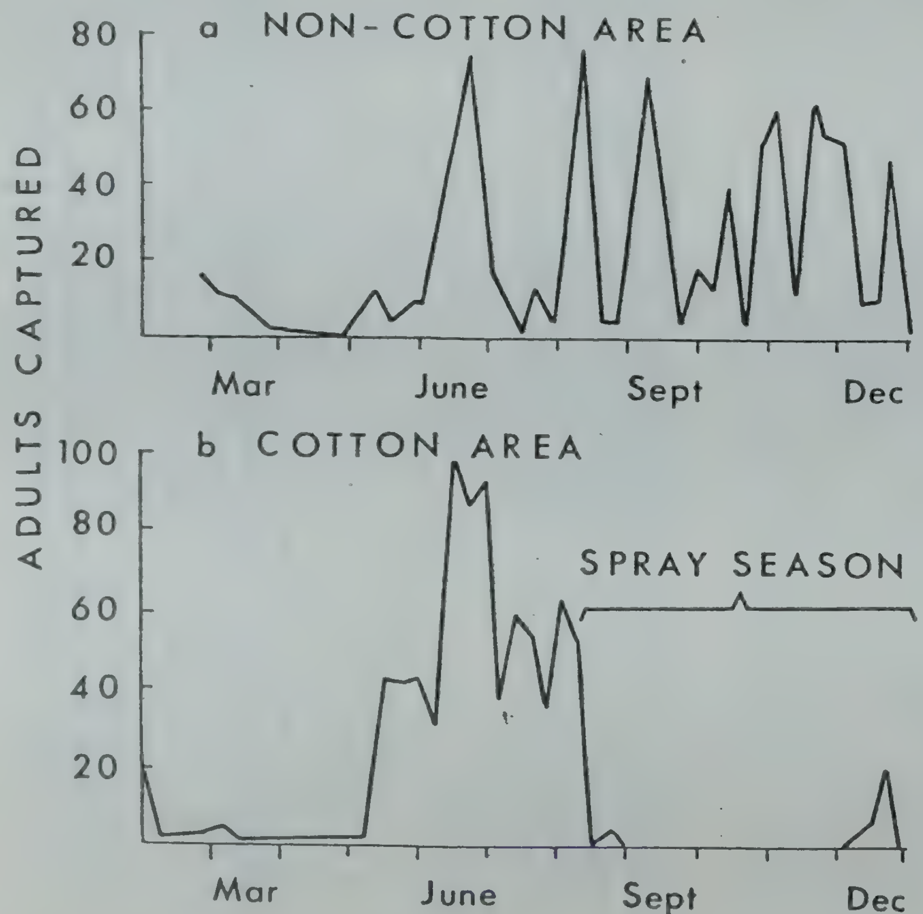

Fig. 2. Catches of adult A. albimanus in a non-cotton and a cotton area

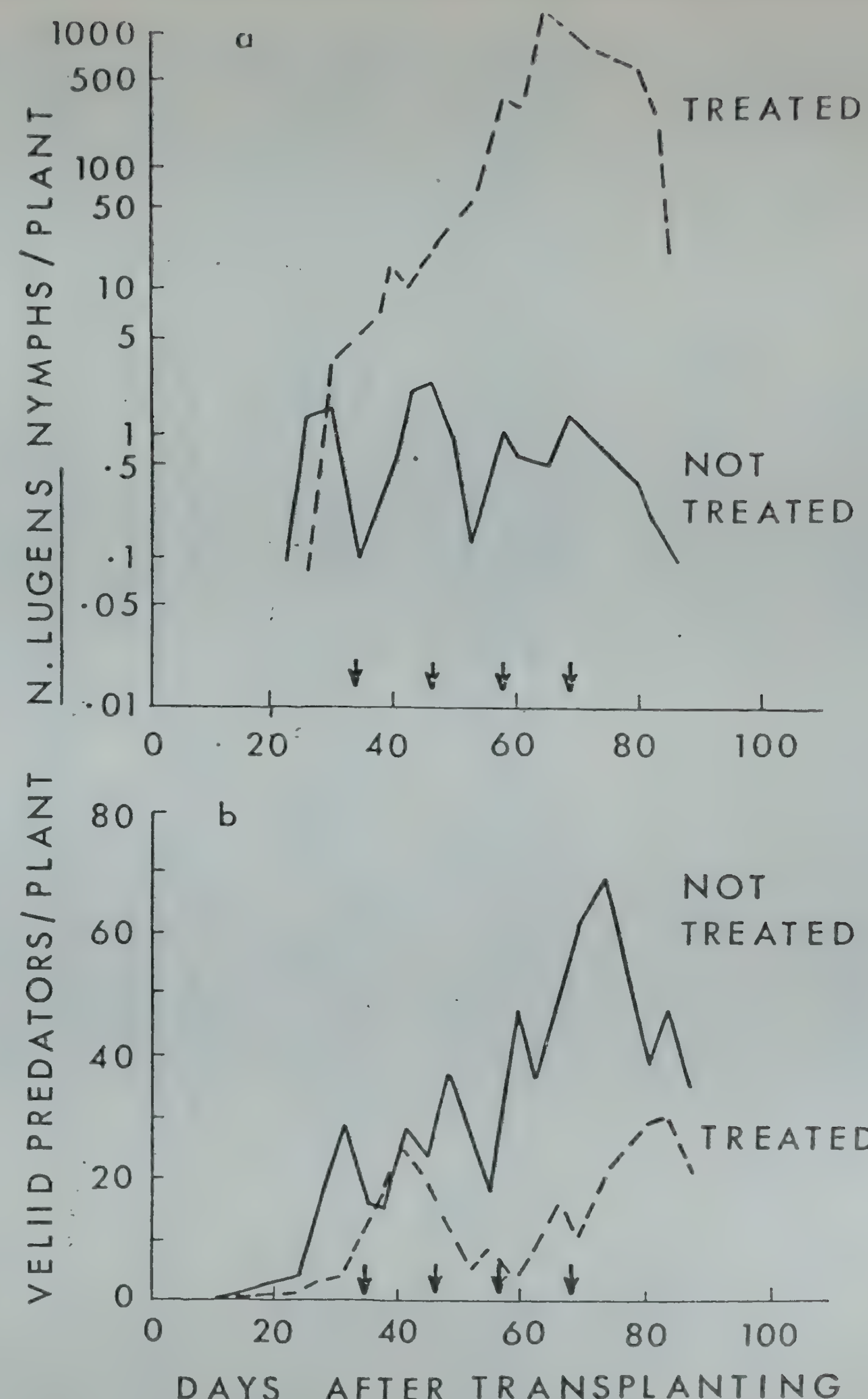

Fig. 3. Population changes of the brown planthopper N. lugens and of its veliid predators in an untreated rice field and a field treated (arrows) once with the insecticide diazinon (OP) and the three times with deltamethrin (pyrethroid) (Kenmore et al., 1984).

19. THE GREEN REVOLUTION IN INDIA AND ECOLOGICAL SUCCESSION OF MALARIA VECTORS

V.P. Sharma[1]

Introduction

In India the green revolution began with the introduction of the High Yielding Varieties (HYV) programme in 1966. Increased agricultural production required the introduction of high yielding rice varieties, intensive methods of agriculture, improved irrigation to minimize dependence on the monsoon, and the use of agrochemicals.

The green revolution coincided with the resurgence of malaria. In 1958 the National Malaria Eradication Programme (NMEP) was launched, and malaria incidence reached a minimum of 100 000 cases in 1965. However, after 1965 incidence increased and reached a peak of 6.4 million in 1976. Insecticide resistance in mosquitoes was considered one of the important factors responsible for malaria resurgence. In 1981 Chapin and Wasserstrom considered that "resurgence of malaria in Central America and India seems to have been parallel to intensified agriculture in these countries and the associated increased use of pesticides".

A critical study by Sharma and Mehrotra (1982 a & b, 1983, 1986) of the Indian scenario of malaria resurgence revealed that malaria resurgence was not directly linked to the green revolution, but that four other factors were mainly responsible: (i) the shortages of DDT throughout the period of resurgence, (ii) the fact that 96 units remained in the attack phase after the experience of more than 12 to 14 years of spraying practice had shown this approach did not interrupt transmission, (iii) the absence of intensive anti-vector measures in urban areas and (iv) surveillance in many areas was not properly organized and health services were not mature enough to undertake vigilance in the maintenance phase. Further analysis of data revealed that malaria outbreaks preceded the true onset of insecticide resistance in malaria vectors and that usage of pesticides in agriculture did not induce resistance at a time when malaria resurgence was already widespread.

Thus, malaria resurgence occurred independently of the green revolution. Nevertheless, changed agricultural practices, irrigation expansion and migration of agricultural labour may have had a profound effect on the mosquito vector fauna, on the epidemiology of vector-borne diseases and, in particular, on malaria transmission. Some of these factors are reviewed in this paper.

Irrigation

The essential goal of irrigation development in India is to increase agricultural production to feed a growing population. India's food production in 1951 was 52.6 million tonnes and gradually increased to 150 million tonnes in 1985. The population increased from 350 million in 1951 to and 768 million in 1981, and is expected to reach

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a figure of 950 to 1000 million by the year 2000 A.D. Irrigation development has been given highest priority in the 20-point programme of the Government of India. In the 1950s and the early 1960s the country was afflicted by a drought-flood-drought syndrome, due to uneven water availability in space and time. For the successful introduction of high yielding varieties reliable water supply was a first requirement. The ultimate irrigation potential in the country is 113 million ha. The total area under irrigation in India before launching of the 5 year plans was 22.6 million ha., while at the end of the 6th plan (1980-85) 75 million ha should have been brought under irrigation.

Unfortunately, mosquito breeding is often considerably enhanced as a result of irrigation development. Additional mosquito breeding sites may be created throughout the network of tributaries, channels and fields. These mosquitoes may be the vectors of malaria, filariasis or Japanese encephalitis. The commonly encountered reasons for irrigation associated malaria are the rise in sub-soil water resulting in water logging, poor drainage, minor engineering aberrations such as leaky sluice gates, seeping canal banks, borrow-pits, defective distribution chambers, improper delivery of water, poorly maintained canals, banks and beds, absence of sufficient numbers of bridges, general water untidiness, absence of a controlled system of field channels, increased wet cultivation and lack of coordination between different agencies (Rao, 1945; Rao and Nassiruddin, 1945).

Russell (1938) stated that it was not irrigation **per se**, but defective and untidy irrigation which, by misplacing water to the advantage of certain species of anopheline mosquitoes, generates malaria. Adequate corrective measures and proper maintenance of irrigation systems may reduce or eliminate mosquito breeding. Surface irrigation, in particular, also increases the average humidity of the atmosphere, thus making the environment more conducive to mosquito survival. This produces a profound effect on the basic reproduction rate and enhances transmission (Sharma & Mehrotra, 1982 a). In contrast, tubewell irrigation is less conducive to mosquito proliferation. In a recent study Sharma and Uprety (1982) demonstrated that villages bordering canals had a very high incidence of malaria, whereas in villages with tubewell irrigation the incidence of malaria was very low.

Mosquito fauna

Knowledge of the mosquito fauna in India is mainly based on the work done before the launching of the National Malaria Control Programme (NMCP) in 1953. With the availability of DDT and other residual insecticides all emphasis was placed on the eradication of disease. As a result, for a period of about 3 decades, almost no information was collected on the dynamics of the mosquito fauna in the country. During this period there have been vast ecological changes in India. The human population has increased from 350 million in 1951 to 768 million in 1981, rural areas have been urbanized and existing urban areas have expanded. Land under irrigation has tripled on and large areas have been deforested and industrialized. In agriculture, the green revolution was launched in the country in 1966. Improved crop husbandry required the application of fertilizers and crop protection from insect pests and diseases. Obviously, insecticide application increased enormously. All these activities brought about a succession of species. Recent surveys by the Malaria Research Centre revealed that various anophelines recorded earlier were replaced by other species (Table 1).

The Terai region in the district Nainital (Uttar Pradesh) is well known for its green revolution. Early studies (Clyde, 1931; Chakrabarti 1954, 1955 a) showed that the region was hyperendemic for malaria. The incidence of **Plasmodium falciparum** was three times higher than that of **P. vivax** (Srivastava and Chakrabarti, 1952). Early

TABLE 1: RESULTS OF MOSQUITO FAUNA SURVEYS

NEW SPECIES RECORDED	SPECIES RECORDED EARLIER BUT FOUND ABSENT
1. ANDAMAN ISLANDS	
(Nagpal and Sharma, 1983)	(Christophers, 1912; Covell, 1927)
A. annularis A. nigerrimus A. nivipes A. karwari A. stephensi A. subpictus A. varuna	A. aitkenii A. umbrosus
2. UTTAR PRADESH, TERAI	
(Nagpal et al., 1983)	(Issaris et al., 1953)
A. aitkenii A. lindesayi A. kochi	A. karwari A. minimus
3. KUTCH + BHUJ	
(Neeru Singh et al., 1985)	(Afridi et al., 1938)
A. aconitus A. nigerrimus A. pulcherrimus A. sundaicus	A. barbirostris
4. ORISSA	
(a) Coastal districts	
(Nagpal and Sharma, 1986)	(Covell, 1942)
A. minimus A. pulcherrimus	A. sundaicus A. theobaldi
(b) Plain districts	
(Nagpal and Sharma, 1986)	(Watts, 1924)
A. aconitus A. ramsayi	A. varuna A. jeyporiensis A. theobaldi A. jamesii

TABLE 1: RESULTS OF MOSQUITO FAUNA SURVEYS (continued)

NEW SPECIES RECORDED	SPECIES RECORDED EARLIER BUT FOUND ABSENT
4. ORISSA (continued)	
(c) Hill districts	
(Nagpal and Sharma, 1986)	(Senior White, 1937; 1938)
A. kochi	**A. moghulensis**
A. ramsayi	**A. majidi**
	A. stephensi
5. NORTH-EASTERN REGION (ASSAM, MEGHALAYA, ARUNACHAL PRADESH & MIZORAM)	
(Nagpal and Sharma, 1987)	(Vishwanathan et al., 1941; Mortimer,1946 and Sen et al., 1973)
A. majidi	**A. balabacensis**
A. theobaldi	**A. aitkenii**
A. nivipes	**A. bengalensis**
A. maculatus var willmorei	**A. culicifacies**
	A. insulaeflorum
	A. lindesayi
	A. umbrosus

attempts to colonize the Terai were unsuccessful mainly because of high morbidity and mortality due to malaria. The situation took a dramatic turn with the availability of DDT. Initially, between 1947 and 1949, three colonization units were opened in the Terai. These units made important contributions in understanding the epidemiology of malaria and determining the dosage of DDT. Subsequently, these units were merged with NMEP units. The spraying of DDT under the auspices of the NMEP eradicated malaria from the Terai in the early 1960s. As a result vast areas of jungle and barren land were converted to agricultural farms. To increase agricultural production several dams were constructed for irrigation. Today the Terai area is well irrigated by a network of canals and their tributaries and boreholes.

Over the past three decades, malaria vector populations in the Terai region have undergone major changes both in species occurrence and densities. On the basis of early studies (Clyde, 1931; Das, 1930) **Anopheles minimus** was considered the primary vector in this region and **A. fluviatilis** was considered zoophilic and of no importance in malaria transmission. However, further dissections of **A. fluviatilis** established its role in malaria transmission. Based on these later studies Srivastava and Chakrabarti (1952) considered **A. fluviatilis** to be the main vector, and it was hypothesized that **A. culicifacies** played a supplementary role in malaria transmission during the autumn months only.

Studies in the Terai region by the Malaria Research Centre in 1979 revealed that **Anopheles culicifacies** was the only vector found in sufficiently high densities to be responsible for the current level of malaria transmission. There was complete absence

of **A. minimus** and **A. stephensi**. **Anopheles fluviatilis** was collected in small numbers from certain pockets (Sharma **et al.**, 1984). **A. culicifacies** was therefore incriminated as the current primary vector supported by **A. fluviatilis** in some locations; an intense transmission of malaria is maintained by these vectors. During 1984, 14 507 fever cases reported for a malaria test at the MRC clinic and of these, 7 885 cases (54.4%) were positive for the malaria parasite, i.e., 5 493 **Plasmodium vivax** (Pv, 37.9%), 2 333 **P. falciparum** (Pf, 16.1%) and 59 mixed (Pv + Pf, 0.4%) infection (Malhotra **et al.**, 1985 a).

In Orissa **Anopheles sundaicus** was the primary vector of malaria in Chilka lake and the coastal areas, with a secondary role for **A. annularis** (Senior White, 1937a; Covell & Singh, 1942 and Panigrahi, 1942). From similar studies it was concluded that in the remaining part of Orissa the members of the fluviatilis group (**A. fluviatilis**, **A. minimus**, **A. varuna** and **A. aconitus**) were the vectors of malaria.

Summarizing the earlier findings on malaria vectors of Orissa, the Manual of Malaria Eradication Operation (1960) states that although twelve species of **Anopheles** are found in this area, only **A. fluviatilis**, **A. varuna** and **A. minimus** play a part in the transmission, in the order mentioned. At the time, **A. culicifacies** did not seem to have any role in the transmission in this area, though the species is not absent. **A. sundaicus** has made a dramatic withdrawal from the coastal areas of Orissa and Andhra Pradesh. It is now found in the Andaman and Nicobar Islands in densities high enough to maintain transmission, and a small focus was discovered in 2 PHCs of Kutch (Singh **et al.**, 1985). In Orissa **A. culicifacies** has assumed the role of primary vector (Nagpal and Sharma, 1986), while **A. fluviatilis** may be responsible for malaria transmission in small areas and **A. annularis** may be playing a secondary role in transmission.

A. minimus was the most important vector species in the Himalaya foothills and North East India. This species was highly susceptible to DDT, and with the launching of the National Malaria Eradication Programme its populations dwindled to extremely low levels. However, recent surveys have re-established the role of **A. minimus** in malaria transmission in N.E. India (Bhatnagar **et al.**, 1982; Das and Baruah, 1985) and a focus of **A. minimus** was also found in coastal villages in Orissa (Nagpal and Sharma, 1983). Although intensive surveys have not been done, it is likely that **A. minimus** may have surfaced in much larger areas. It is a highly efficient vector of malaria and its re-appearance can bring back active malaria transmission in areas of its distribution. Recent surveys in the northeastern states show very low densities of **A. dirus** (Nagpal, 1987). In the past, when this vector occurred in high densities, it was responsible for a considerable part of the malaria transmission. It is likely that small pockets may still be rich in **A. dirus**, but it is certainly not the main vector responsible for maintaining high malaria transmission in that region now.

In Bengal and Assam, high densities of **A. philippinensis** used to be found, while in other parts of India this species was scarce. Based on mosquito dissections between 1936 to 1939, Iyengr (1940) reported important vectors of malaria in Bengal as being **A. philippinensis** in the plains, **A. minimus** in the foothills and **A. sundaicus** in the estuarine region. Meanwhile, **A. sundaicus** populations have dwindled and only a small focus may still be existing in Sunderbans. An outbreak of malaria in the Durgapur steel plant area in Bengal was attributed to **A. stephensi** and **A. culicifacies** (Arora, 1961). **A. philippinensis** continues to be a vector in Assam. Recent studies by the MRC have shown that the most prevalent species there is **A. nivipes**, although a small proportion resembling the identification of **A. philippinensis** has been encountered (Nagpal, 1987), but it is not at all clear whether it is the true **A. philippinensis** or a variant of **A. nivipes**. Cytotaxonomical studies are in progress to resolve this species identification problem.

Rao (1984) reports that **A. fluviatilis** was the major vector of malaria in Thane district (Maharashtra) prior to the introduction of DDT in 1944-48. Since 1958, **A. culicifacies** has become a major vector. It occurs in enormous numbers and is the major cause of persistent malaria transmission.

Anopheles culicifacies complex

On the whole, **A. culicifacies** is the major vector of malaria in India today. Sporozoite positive mosquitoes have been found throughout its plains. **A. culicifacies** transmits **P. falciparum**, **P. vivax** and **P. malariae** (Siddons, 1944 a & b), including cloroquine resistant **P. falciparum** strains. There is epidemiological evidence to suggest that **A. culicifacies** is an efficient vector in North-West India, capable of maintaining intense transmission, but a weak vector in eastern India. It has been responsible for periodic epidemics in several parts of the country. It is estimated that **A. culicifacies** is responsible for about 70% of the new malaria cases every year. It has become resistant to DDT and HCH in most parts of the country and to malathion in Gujarat and Maharashtra. Control of **A. culicifacies** is the major concern of the NMEP and for this reason the research endeavours of the Malaria Research Centre have been focused on this species.

The first report of cytological identification of sibling species complex in **A. culicifacies** (comprising species A and B) was given by Green and Miles (1980). Subbarao **et al.** (1983) confirmed the findings and reported that in addition to the already described inversion Xa and Xb, two fixed paracentric inversions were observed on chromosome 2, leading to the recognition of a new sibling species C. A limited survey of the Indian sub-continent revealed the presence of species B in almost all areas of **A. culicifacies** distribution. Species A was sympatric with species B in North West and southern India. In eastern Uttar Pradesh and Bihar species B was almost the only species found. In western and eastern India species B and C were sympatric, whereas in central India species A, B and C were sympatric. Long-term ecological studies showed that species A was the dominant species in the North-West. The proportion of species B is generally less than 10% but in humid conditions it may equal or exceed the numbers of A. Species A was incriminated as a vector in the field, but no specimen of B could be incriminated (Subbarao **et al.**, 1980, 1987 a).

Northern states of India such as Punjab, Haryana and parts of Uttar Pradesh have played a key role in the green revolution. One of the major inputs to increase food production was providing surface irrigation to the vast tracts where agriculture was dependent on the monsoon. A study of the development of malaria incidence over the years revealed that areas at one time prone to fulminating epidemics have now become endemic. Even profuse breeding of **A. culicifacies** under favourable weather conditions does not bring malaria epidemics of the type reported in the past (Christophers, 1911). Irrigation provided innumerable breeding sites for **A. culicifacies** throughout the year. Species A is the dominant species (over 90%), whereas species B populations may rise upto A levels only during the rainy season or in wet areas (Subbarao **et al.**, 1987a). Species A is an efficient vector of malaria. High population densities of species A may be the reason for perennial transmission to a level where immunity against malaria is maintained, thus changing the periodicity of epidemics in favour of endemic and stable malaria. In areas where surface irrigation created conditions conducive to the proliferation of sibling species B, such as eastern Uttar Pradesh and Bihar, there has been no change in indigenous transmission even though human migration is introducing new strains into the area (Subbarao **et al.**, 1987b). These areas were hypoendemic even before the launching of the NMCP/NMEP.

Increased use of pesticides in agriculture may bring about resistance in **A. culicifacies.** Monitoring of resistance in **A. culicifacies** populations in Orissa showed resistance to malathion (Nagpal, 1986). However, in these areas malathion was never used for public health. Malathion is the insecticide used by the NMEP in areas with DDT and HCH resistance. The evolution of resistance to replacement insecticides, such as malathion may make vector control problematic. It was demonstated that DDT-spraying resulted in the reduction of malaria transmission and **A. culicifacies** densities in

otherwise DDT-resistant populations (Sharma **et al.**, 1982, 1986a). Concurrent susceptibility tests and monitoring of sibling species in the field showed that spraying of DDT increases the proportion of species B due to a higher susceptibility of species A (Sharma **et al.**, 1982, Subbarao **et al.**, 1987b). The agricultural usage of DDT may in fact favour the abundance of species B over that of A, and species B has a lower vectorial capacity. Careful monitoring of epidemiological indices should constitute the basis for change of DDT in areas with **A. culicifacies** species A and DDT-spraying should be preferred over other expensive insecticides as long as there is reduction in malaria transmission to acceptable levels.

Rice cultivation

Work on the rice field breeding and control of mosquitoes in India started in late 1920s and 1930s and has been reviewed by Senior White (1946), who quotes Christopher as follows: "The relationship of malaria to rice cultivation is of great importance. Wet riceland under certain circumstances is definitely associated with malaria, but extensive tracts of rice cultivation are often notable for low spleen rates present. Passing from the jungle and grass Terai land with high spleen rates, it is not uncommon to encounter as soon as the flatter, wetter riceland is entered, a quite low spleen rate".

A variety of mosquitoes breed in rice fields, but several investigators have shown that **A. culicifacies**, has very limited breeding in rice fields themselves. The main breeding sites are the fallow fields and irrigation channels (Watts, 1924; Sen, 1935; Russell **et al.**, 1938). Also, the limited breeding of **A. culicifacies** takes place only until the plants are 30 cm. tall. Beyond this period mechanical obstruction is the chief factor for keeping **A. culicifacies** out of rice fields (Russell and Rao, 1942). Of the other malaria vectors, **A. annularis** and **A. philippinensis** have been demonstrated to be rice field breeders (Clyde, 1931; Sen, 1935 and Thompson, 1940). **A. minimus** breeds in channels but not in rice fields (Stickland, 1925; Thompson, 1940). **A. fluviatilis** was most common in North Kanara during the monsoon in fallow rice fields (Singh and Jacob, 1944). However, later Rao (1945) emphasized the importance of rice field breeding of **A. fluviatilis**.

A one year study in Uttar Pradesh (the Terai) on the breeding ecology of anophelines by Sharma **et al.** (1984) showed that 50% of the larvae collected from the rice fields were **A. culicifacies**, 12% **A. annularis**, 1% **A. fluviatilis** and 26% **A. subpictus**. Although **A. culicifacies** is the major vector (Choudhury **et al.**, 1984), its proportion in rice fields was 1.7% against 62% in river bed pools, 10% in borrowpits, and 13% each in irrigation channels and ponds. Similarly, **A. annularis** did not prefer to breed in rice fields. Most of the breeding was that of **A. subpictus** which is not a vector in this region. We have also analysed data of the total area under rice cultivation in two states of North India, one in the West (Punjab) and one in the East (Bihar). In Punjab the area under rice cultivation started at low levels and reached the levels of Bihar in the early 1980s. The malaria picture in the two states was quite different, e.g., Bihar which had a large area under rice had very low incidence of malaria as against Punjab, where malaria resurgence seems to have some parallel with rice expansion.

Russell and Rao (1942) reported that intermittent irrigation (2, 3, or 4 dry days followed by 5 wet days) prevented mosquito production. The method not only prevented mosquito breeding, but was not detrimental to the crop yield (Russell **et al.**, 1942; Russell and Knipe, 1942). However intermittent irrigation is not practised in India because of unreliable water supply and lack of knowledge of the technique.

Crop rotation could reduce mosquito breeding. Generally, rice is rotated with a non-rice crop. A recent development due to irrigation is that in many states like Karnataka, Tamil Nadu and Andhra Pradesh two or three crops of rice are taken annually, thus providing extensive mosquito breeding grounds throughout the year. The practice of crop rotation is beneficial in reducing mosquito breeding. There is a need for studies on the impact of growing two or three consecutive crops of rice on mosquito vector breeding, and consequent disease transmission.

Migration

Migration of the temporary labour force for agriculture mainly takes place during the harvest and sowing seasons. Migration may disseminate infection from endemic to non-endemic areas. Population migration for agricultural and construction activities is complicating the malaria situation, particularly with respect to the chloroquine resistant **P. falciparum** strains. There is a regular back and forth movement of labour from Bihar, West Bengal, Orissa and Madhya Pradesh to northeastern states. Some areas of northeastern states and Orissa are known for a high incidence of **P. falciparum** malaria and the problem of drug resistance (Sharma, 1984). This inter-mixing of population introduces malaria and new parasite strains in areas free from the disease. In tropical conditions indigenous transmission gets established quite easily. In a recent study, movement of labour for agricultural purposes was monitored in Nadiad taluka where malaria is controlled using bio-environmental methods. In this area malaria cases have been reduced to low levels (Sharma **et al.**, 1986), but inward movement of parasite positive cases is introducing new strains into the area. Monitoring of labour movement from areas outside Nadiad taluka revealed 2 to 7% SPR in the first quarter of 1987 (Sharma, 1987).

Conclusions

1. The green revolution was not the cause of malaria resurgence in the country. Although it was hypothesized that increased usage of insecticides to protect HYV contaminated mosquito breeding sites and induced resistance in the vector species, malaria outbreaks preceded the true onset of insecticide resistance in the vector species.

2. Irrigation systems have made the areas more conducive for mosquito proliferation. Poor canal maintenance and untidy irrigation is responsible for creating conditions favourable for mosquito vector breeding.

3. There have been major changes in mosquito fauna as a result of developments that have occurred in about the last 3 decades or so. In areas under green revolution or intensive agriculture, succession of new species has occurred in many parts of the country, thus changing the malaria transmission potential of these areas.

4. The most commonly encountered mosquito breeding sites of malaria vectors are the channels and fallow fields rather than rice fields **per se**. Rice cultivation may be harmful in certain specific situations but a study of the Indian scenario revealed that rice cultivation has a very weak or no relationship with malaria transmission. This conclusion is mainly based on information from regions which follow crop rotation and grow one crop of paddy per year. Canal irrigation is bringing about changes in the agronomic practices. In many Indian states instead of rice and non-rice crop rotation two or three crops of paddy are grown

in one year. This may allow continuous breeding of vectors. Regular monitoring of vector breeding is required to delimit the impact of changing agricultural practices on mosquito abundance and consequent enhancement of disease transmission.

5. The sibling species complex in **Anopheles culicifacies** profoundly affects malaria transmission in different parts of the country.

6. Inward and outward population migration, **inter alia** for agricultural work, is disseminating new malaria parasite strains to areas free from the disease.

20. THE LINKAGE BETWEEN MECHANIZATION OF AGRICULTURAL PRACTICES FOR RICE CULTIVATION AND VECTOR-BORNE DISEASE TRANSMISSION

M.W. Service[1]

Farm mechanization

The increase in rice production that has occurred in the developing countries, and which must continue, is largely being achieved by mechanization, but agricultural mechanization on rice irrigation schemes, as well as intensity of labour, usage of pesticides and fertilizers, varies greatly from country to country and even from area to area. Mechanization will undoubtedly have to increase to meet the projected world demand for rice in the year 2000, that is an 86% increase over the 1974-1976 crop yield (Tsutsui, 1984). Mechanization can be defined as any mechanical means that facilitates agricultural production and reduces drudgery, and includes methods of preparing fields for crop planting and harvesting them, such as tillage, ploughing, harrowing, threshing, as well as weed control.

In 1970 there were an estimated 15.6 million 4-wheel tractors and crawler tractors in the world, but only 1.3 million were in the developing countries (FAO, 1974). Economic, technical and political factors greatly affect the speed with which mechanization is introduced. In the developing countries mechanization seems to be proceeding fastest in South East Asia. However, in East Asia only Japan is fully mechanized in rice production. The next most mechanized countries are China, Taiwan, Korea and Sri Lanka. Malaysia is likely to be the next country to adopt rice mechanization (Herdt, 1983). Land preparation is usually the first activity to be mechanized, and considerable progress has been made in the Philippines and Thailand. In Thailand, for example, mechanization dates back to the early 1970s, and, through the IRRI-Thai Mechanization Project, tractor use, as seen from table 1, has recently increased dramatically (Cochran, 1984). By 1983 the number of 2-wheel tractors had increased to about 350 000, and that of threshers to some 22 000.

Table 1. Trends in mechanization in rice production in Thailand over the period 1961-1977.

	1961	1977	% increase
2 wheel tractor	151 504	284 351	87
4-wheel tractors	23 942	31 158	63.5
Large tractors	22 826	50 044	119.2
Water pumps	317 328	603 548	90.2
Threshers	4 962	20 601	315.2

The sixth five-year plan for Thailand's economic and social development (1987-1991) stresses the need for promoting mechanization to increase land production output.

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But it is recognized that at present mechanization may not be appropriate for all farming conditions and societies; for instance, in the northeastern areas the emphasis is not so much on replacing ox-drawn ploughs with tractors, but on improving the design of the ploughs.

Impact of mechanization on farming

Mechanization can lead to (i) a change in the numbers of farm labourers or their re-deployment; (ii) increase in plot size or farm hectarage; (iii) increase in crop yields; (iv) more crops per year; (v) change of land usage, and (vi) decrease in farm livestock, as well as a variety of social and economic changes. It is, however, difficult to predict any of these changes as they will vary greatly according to local customs and traditions, as well as to farm economy. For example, mechanization often leads to a reduction of farm labour, but this is not a universal consequence. In Nepal and Indonesia the introduction of mechanization in the form of tubewells and pump irrigation has increased the demand for labour throughout the year. In the Philippines, mechanization caused a significant reduction of people needed for land preparation, although in fact the total labour force was little affected due to redeployment (Aguilar **et al.**, 1983). In Bangladesh mechanization has not always altered the number of farm workers, although their employment often changed from that of labourers to plot owners. In one study in West Java, however, mechanization resulted in less labour (Saefundin **et al.**, 1983). Hidajat (1982) concludes that mechanization in Java initially reduced demand for agricultural labourers, but since 1978 several studies have shown that mechanized agriculture is being promoted by an insufficient supply of farm labourers. Indications are that if mechanization leads to increased rice hectarage then there will follow a demand for extra labour.

Mechanization may also increase the size of plots and cause a reduction in the numbers of independent farmers, although this may be accompanied by a greater number of cooperatives. Duff and Kaisen (1984) discuss changes in rural labour associated with mechanization. Further information on the effects of mechanization on employment is given by Ahammed and Herdt (1984) and by Farrington **et al.** (1984), the latter being a most useful publication as it contains many statistics, at least up to 1980, on the degree of farm mechanization in different Asian countries.

Although mechanization reduces the turn around time (the time from harvest of one rice crop to planting of the next), that is not always considered to be of great benefit. In West Java farmers bought tractors to ensure planting rice on time, to plough deeper and to reduce land preparation costs, but none was interested in planting an additional third crop (Aguilar **et al.**, 1983). Other times, however, farmers have grasped the opportunity of planting an extra crop. In Nepal, for example, the introduction of pump irrigation, and in Indonesia the installation of tubewells have increased the number of rice crops a year as well as rice crop yields. There may also be changes in the type of crops grown. In Bangladesh, for instance, mechanization has led to a decrease in rice production, other crops being grown instead . In many other instances, however, such as in Pakistan, where a farm mechanization policy started in 1970, there has been an increase in both farm size and rice-growing areas.

The traditional method of tillage before transplanting rice is ploughing and puddling, and in many countries puddling still remains the usual method of preparing fields for rice transplantation. It gives good weed control, reduces water loss through percolation, and gives higher crop yields, but instead of puddling soil, compacting followed by flooding can be undertaken. For example, after the first ploughing and harrowing in dry condition, heavyrollers or loaded-wheel tractors which repeatedly compact the soil can be employed. Such mechanization is much more efficient in eliminating pockets in the soils than puddling, and decreases the water requirements for rice cultivation.

Animal traction has been the principal source of energy in Asia and other countries for many years, but mechanization of land preparation is now becoming increasingly common, at least in East Asia (Yoshida, 1984). Animal-drawn ploughs rarely dig deeper than 10 cm, nevertheless in Bangladesh ploughing two to three times a year increases rice production by almost 1 ton per hectare. In the Mekong Delta ploughing is shallow, but repeated harrowing, up to 7-8 times a year in the rainy season before rice transplanting, reduces weeds and increases rice yields.

The cultivation of deep peat soils with mechanized ploughs is problematic because the ground becomes water-logged and the tractors become bogged down unless large diameter wide wheels, cage-wheels, tracks or floats are used. Mechanized transplanters can reduce the man-hours/hectare from 157 for manual transplanting to 42 man-hours (Igbeka, 1984), and mechanized transplantation is becoming very popular in Malaysia, Thailand, Iran, Pakistan, Japan, China and Korea.

Agricultural mechanization is also usually associated with increased usage of fertilizers, herbicides and insecticides. This obviously has impacts on vector populations such as mosquitos, and may promote insecticide resistance in them.

Impact of mechanization on vectors

Although the introduction of mechanization into rice cultivation is well documented (e.g., Wicks, 1983) there is extremely little information on its effect on vector populations and the epidemiology of disease. Nevertheless, a few specific examples can be cited, and some generalizations made.

Mechanization, such as use of tractors, makes it practical and economic to cultivate marginal lands, and scrub lands and forests may be cleared and put under cultivation. Ecological changes such as these and the creation of monocultures, can have far-reaching consequences on disease transmission. Farm mechanization can also alter the life-style of people, possibly increasing, for instance, the mobility of migrant and seasonal labour which might result in the introduction of new diseases, although on the other hand the resident rural population exposed to the risk of contracting these introduced diseases may, in fact, decline. As economic growth expands, farmers and their employees may live in better constructed houses, which may be further away from irrigated fields, and this could affect the man-mosquito contact. With rice cultivation, mechanization is likely to be associated with increased areas under flooding and consequently larger mosquito populations, unless there are other changes that counteract this, such as the introduction of so-called "dry" rice varieties which result in fields becoming flooded for shorter periods. Generally, the introduction of mechanized farming will be a relatively slow process, accompanied by gradual environmental changes, and it will be very difficult to predict the impact it will have on vector-borne diseases.

Any method that reduces weeds should help reduce populations of snail intermediate hosts of schistosomiasis, and may also reduce mosquito breeding, or change mosquito species composition. Mechanized weeding is sometimes employed on rice paddies, and rotary weeders are becoming increasingly popular. The use of weed machines on the Gezira scheme in Sudan to clear weeds from canals has indicated there can be a marked reduction in snails, but some weeds such as **Vossia cuspidata**, **Potomageton perfoliatus**, **Typha** spp. and **Cynodon dactylon** are not completely removed, and snails can be found attached to both floating and cut pieces of these weeds, and also to uncut fixed parts (PEEM, 1984).

Preparing fields with oxen and other draught animals may take 7-10 weeks for lowland rice, whereas tractors and other types of mechanization can shorten the land

preparation time and cut deeper (10-20 cm) into the soil. In Texas, Owens **et al.** (1970) found that appropriate tillage practices, such as ploughing prior to flooding, could at least in small plots and playa lakes (hard clay depressions), reduce the numbers of certain **Aedes** and **Culex** mosquitos. While in the Tennessee Valley region Cooney **et al.** (1981) obtained excellent control (73-100%) of floodwater mosquitos, especially **Aedes vexans**, by ploughing followed by discing. Control was achieved largely through **Aedes** eggs becoming buried so that resultant larvae were trapped under a layer of soil. On one plot discing was not performed and mosquito breeding was only reduced by about 44%, clearly emphasizing the need to complete the tillage cycle for mosquito control to be effective. This method is applicable only so long as tillage can be undertaken, and will only be effective if this is followed by a single flooding. One problem encountered in many different regions of the world is that with soft clay soils tractors may lose traction and the softening caused by breakage of the "plough sole" layer by large machines may hamper their mobility. Increased ploughing or discing of rice fields can make the habitat unsuitable for snails (Ito, 1970), with the result that most snails on irrigation systems are restricted to irrigation canals and ditches.

The introduction of dryland tillage and dry seeding for rainfed rice, and use of early cultivars in areas having 5-7 wet months a year (at least 200 mm rain/month) allows two rice crops a year. However, this method relies on the availability of low-cost power tillers and small tractors for quick tilling to overcome the problems of inadequate power on small rainfed farms. Twice yearly cropping may result in increased mosquito populations, but this will depend on local practices and environmental conditions, such as how long fields remain flooded and whether pools of water remain after the fields are drained.

Mechanization often reduces livestock. In Pakistan, for example, each tractor has displaced on average 2.0-2.5 bullocks, but not milking cattle. Similarly in Bangladesh, Jabbar **et al.** (1983) reported that although 98% of the land is still cultivated by bullock-drawn ploughs, the relatively few tillers that have been introduced have replaced 2.0-2.5 bullocks per tiller. The classical example of the impact of mechanization on the epidemiology of a vector-borne disease is that reported from Guyana by Giglioli (1963). Prior to the 1960s malaria in the coastal area of Guyana was transmitted almost exclusively by **Anopheles darlingi**, a highly anthropophagic and endophilic freshwater breeding mosquito. Although **A. aquasalis** was about as common as this vector it was strictly zoophagic and exophilic. During the 1946-1950 malaria eradication campaign residual house-spraying with DDT virtually eradicated **A. darlingi**, but it had no effect on the exophilic **A. aquasalis**. Malaria was eradicated in coastal areas including the Demerara river estuary and spraying ceased in 1951. However, in 1961 malaria cases recurred. By then the ecology and socio-economic status of the area had changed. For instance, the human population had increased and most available pastures and fallow lands were converted to rice cultivation, and cattle which formerly occupied them were displaced or eliminated. Mechanization replaced horses, donkeys and mules on the roads, while tractors replaced oxen for ploughing. Because of the deficit of livestock the original zoophagic **A. aquasalis** switched to feeding on man and was responsible for malaria outbreaks on the Demerara river estuary 16 years after malaria had been eradicated.

Conclusions

There is little information on the impact that farm mechanization of rice and other irrigated crops has on the population densities of vectors, or the prevalence of vector-borne diseases. Furthermore, the diversity of economic, social and ecological consequences arising from the introduction of mechanized power makes it extremely difficult to predict its effect on vectors. However, the following are the types of questions that need to be asked - and answered. Will farm mechanization on irrigation

schemes result in (i) more or less standing water during land preparation, during rice growing and post-harvest; (ii) increased or reduced water contact by farm workers; (iii) more or less standing water following the introduction of tubewells and pump irrigation; (iv) increased or reduced rice hectarage; (v) increased number of crop cycles; (vi) marginal lands and forests being cleared, if so how will this affect vector species and their populations; (vii) a reduction of cattle; if so, will vector populations increase or decrease, and will mechanization result in (viii) improved social and economic conditions leading to better housing, and housing further removed from the paddy fields?

The answer to these and other relevant questions will depend much on local circumstances and farm management practices.

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